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GENERAL ELECTRIC REVIEW

VOL. XXVIII, No. 2

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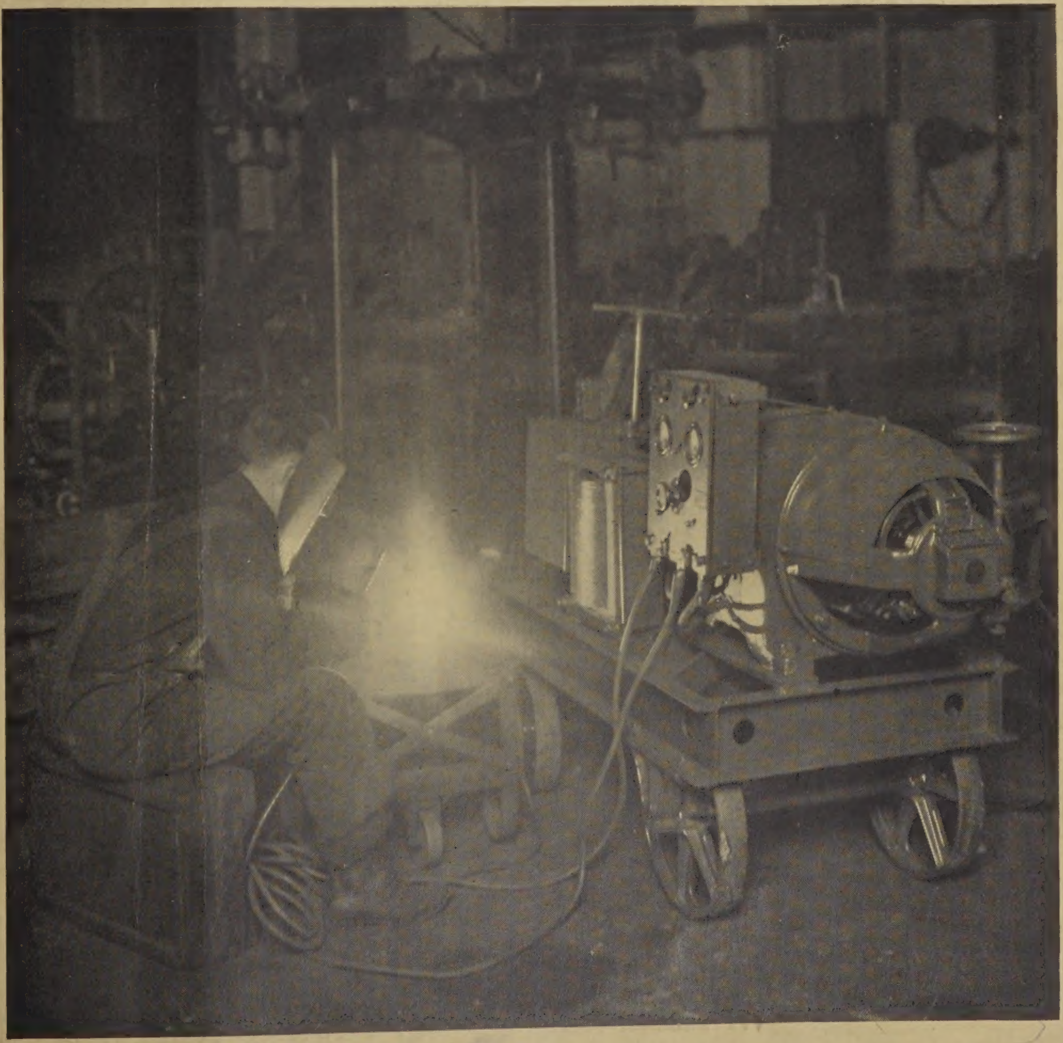
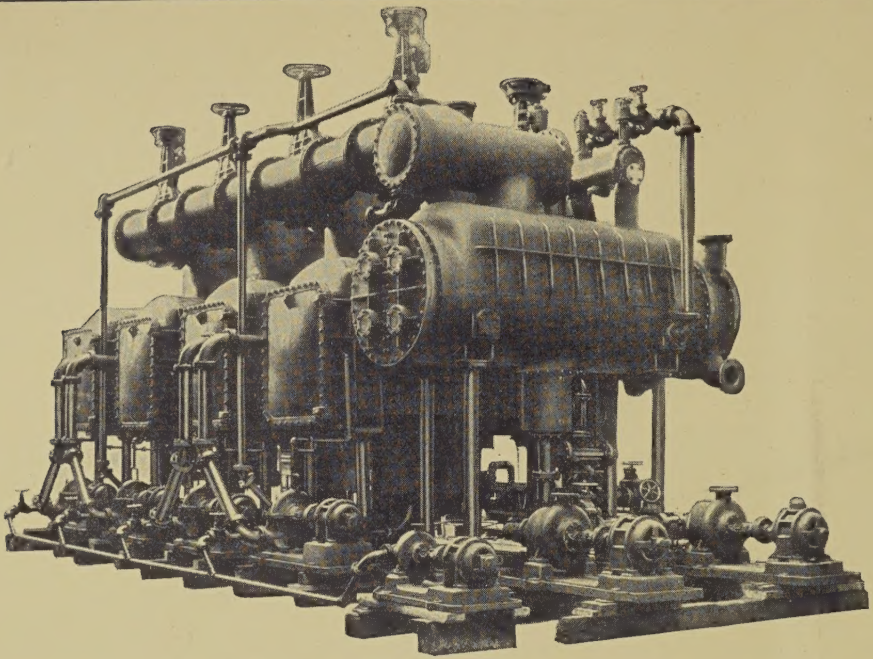


WELDING BY ARC LIGHT

Self-excited Welding Set having an inherently regulated output, adjustable from 75 to 300 amp. by the brush-shifting handwheel on its right. The resulting voltage-current characteristics make this compact set ideal for single-welder operation. (*See article p. 86*)

In This Issue:

Coal Towers
Welding Generator
High-frequency Furnaces
1500-volt Railway Control in Java
Cold Light
Exciter Rheostats
Saw Mill Electrification
A-C. Elevators
Crystal Structure



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BOILER FEED PUMPS
CENTRIFUGAL PUMPS
TURBINES
CONDENSER TUBES
BRASS & COPPER PIPE

THE self-scaling quadruple effect illustrated is installed in the new Philo plant of the Ohio Power Co., a subsidiary of The American Gas & Electric Co.,—Sargent & Lundy, Engineers.

Duplicate unit is being installed in the new Twin Branch Plant of the same company at new South Bend, Indiana.

Continuous operation of modern boiler plants is assured by providing evaporated make-up.

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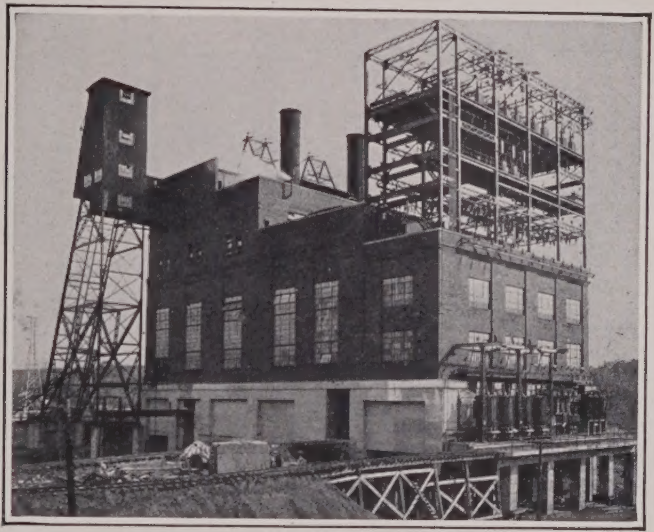

Williamsport (Md.) Station of The Potomac Edison Company.
Ultimate capacity, 160,000 kw.

High Commercial Efficiency

Sanderson & Porter, Engineers and Constructors for the Williamsport (Md.) Station of The Potomac Edison Company, authorize the statement that the coal rate after one year of service, figured on a monthly basis, is 1.48 lbs. per kw. salable energy on the feeder circuits. *The efficiency of energy generation is high.*

The station is of simple design, comprising a 15,000-kw. turbo-generator unit with surface condenser and steel-tube economizer boilers. It was in service in less than one year after construction was started. *The efficiency of invested capital is high.*

The auxiliary drive system is combination steam-electric for isolated transmission line service. **An Elliott Closed Heater** on a turbine stage extracts steam for feed water heating after part of the work energy is utilized. **An Elliott Open Heater** recovers the heat of the auxiliary exhaust steam. **An Elliott Deaerator** protects the economizers, boilers and turbine from corrosion.

The efficiency of Elliott equipment in heat utilization and corrosion protection is high

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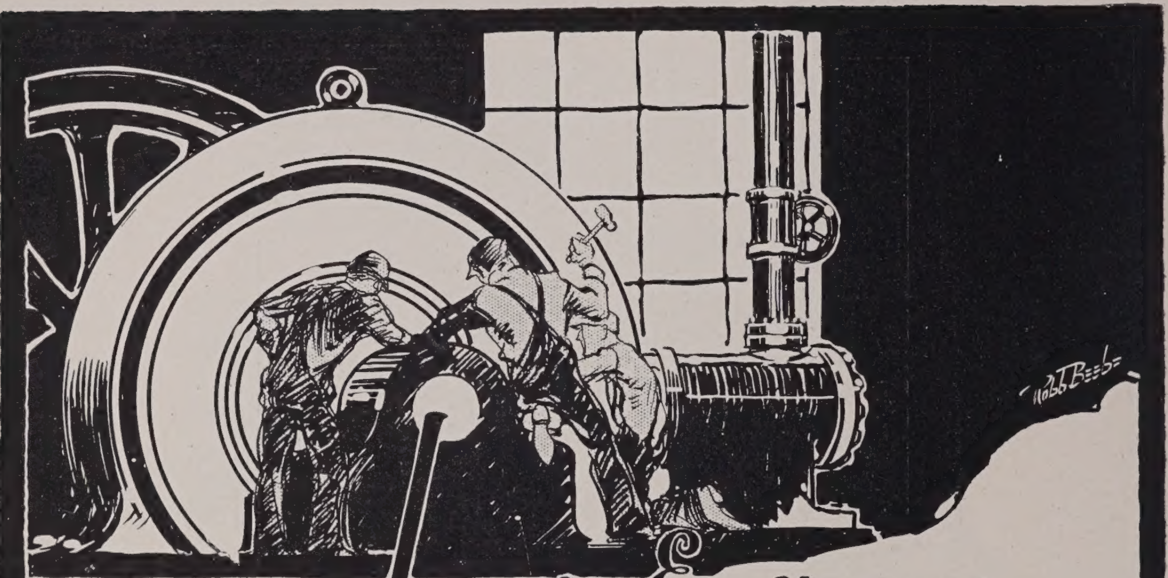
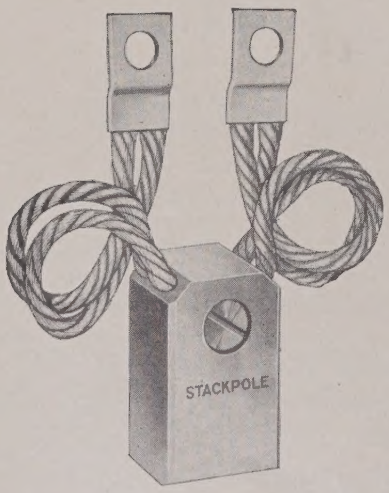


Inactive Equipment
the bugbear of production



Of course, machine trouble may be caused by anyone of a dozen reasons such as faulty design, worn bearings, open circuits, unbalanced armature, and the like.

BUT—with a Stackpole Carbon Brush one common cause of machine failures will be eliminated.

The smooth, glossy commutator that radiates cleanliness and efficiency is a common sight when Stackpole Brushes are on the job. The Stackpole Carbon Brush assures cool operation and perfect commutation with minimum commutator wear.

Stackpole Catalog No. 8 gives information on Carbon Brushes that you will find both instructive and interesting. May we send you a copy?

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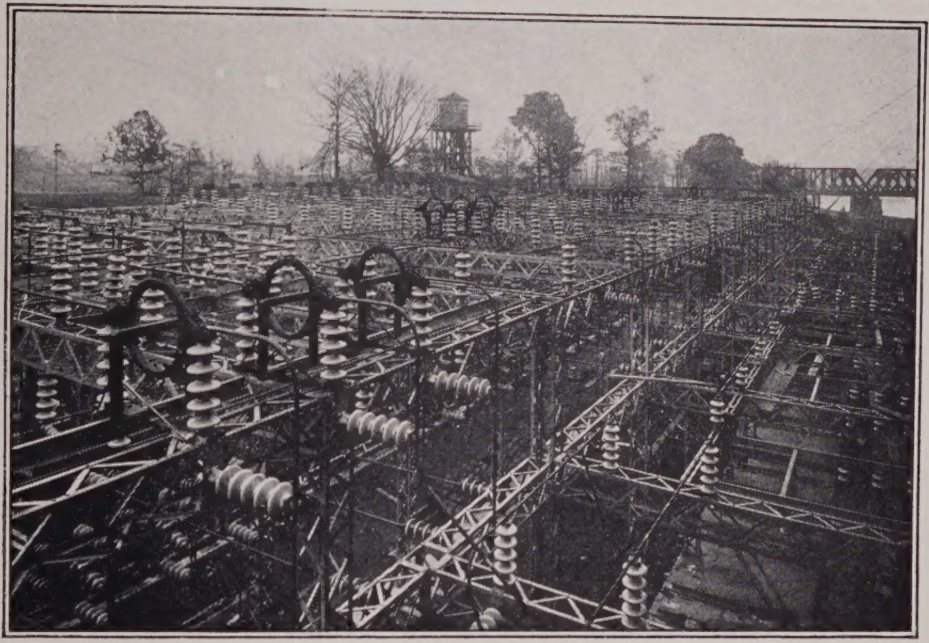
Stackpole carbon brushes



Outdoor Bus Structure—Devon Plant—Connecticut Light & Power Company. Construction Engineers: The J. A. T. Crisfield Co.

Anaconda Copper Tubes for Outdoor Buses

High conductivity Anaconda Copper Bus Tubes were selected for the 66,000-volt outdoor bus structure recently erected for the new Devon plant of the Connecticut Light & Power Company.

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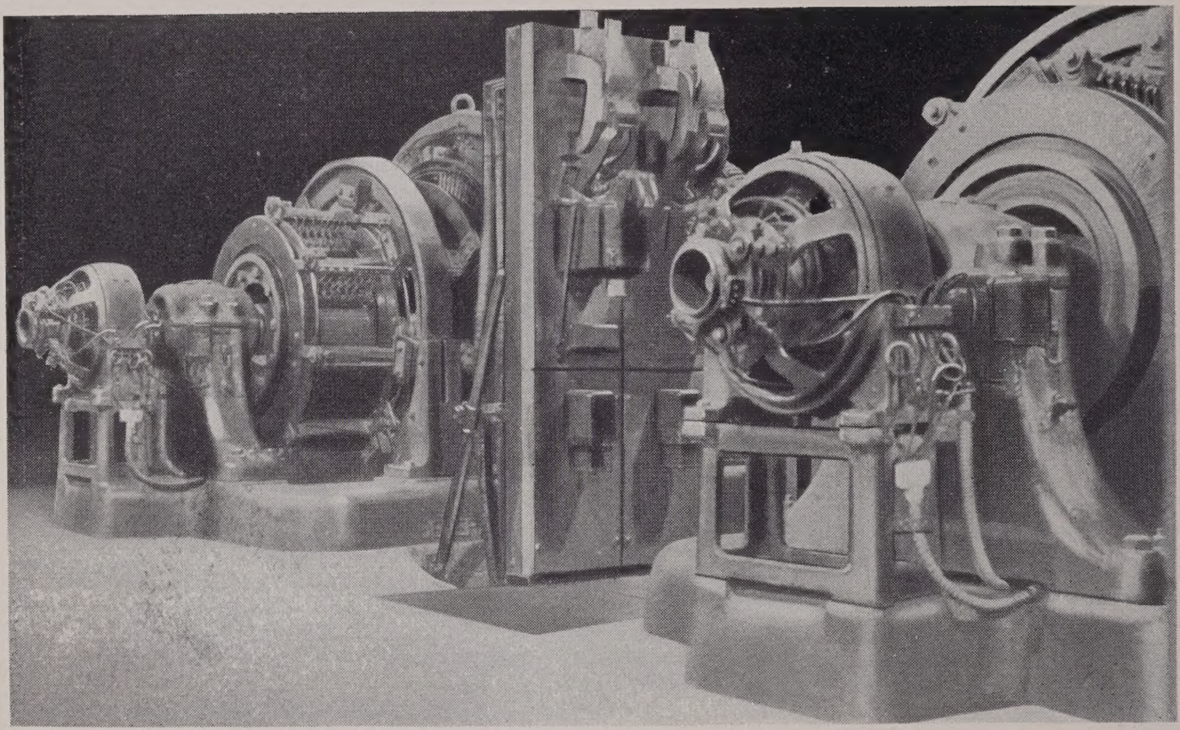

From zero to peak load in 50 seconds

At about 8 A.M. daily the load on Substation No. 1, Indianapolis Light & Heat Co., Indianapolis, Ind., rises to the peak of 6000 amperes in 50 seconds. Operation is fully automatic, the idle one of the two machines having to start instantly and carry its share of the load.

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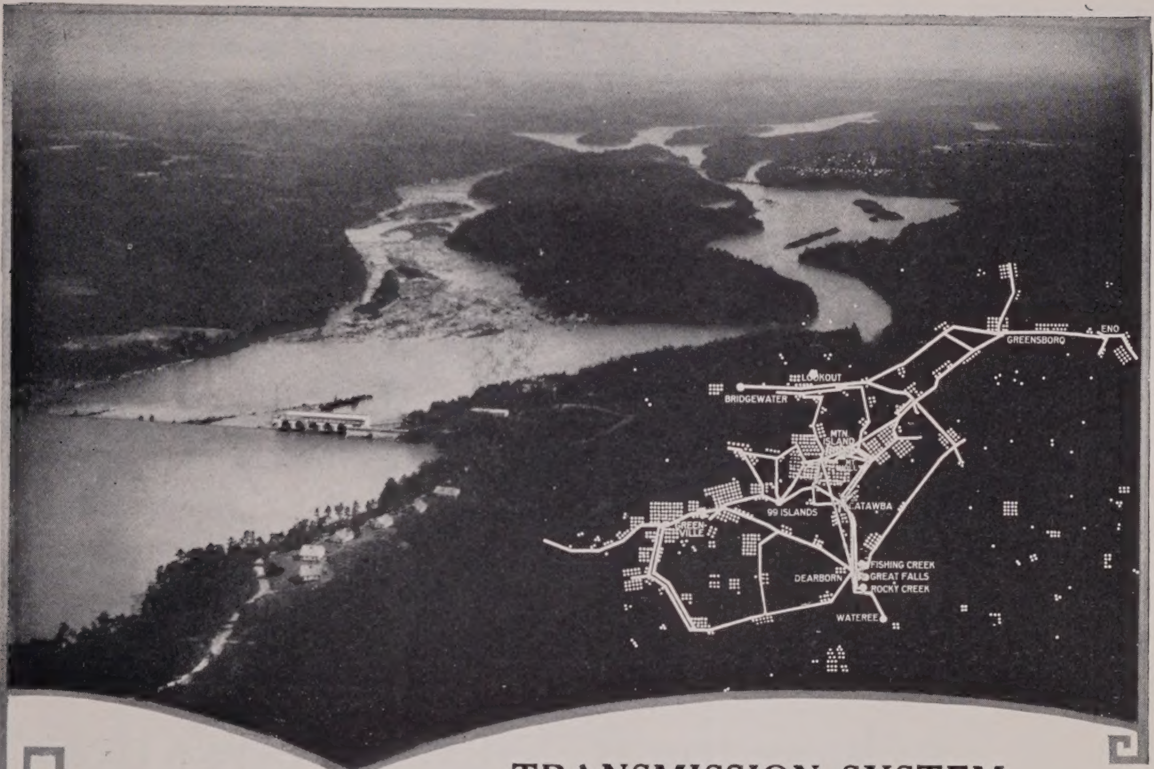
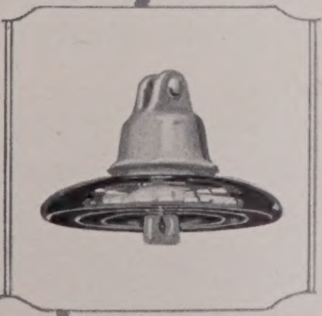
Say you saw it advertised in the GENERAL ELECTRIC REVIEW



TRANSMISSION SYSTEM
OF THE
SOUTHERN POWER COMPANY



The Southern Power Company occupies a position of unique interest, not alone to the industries and institutions of North and South Carolina, but to the entire country. One of the largest of the great electrical systems, its activities and progress in recent years have assisted materially in the rapid development of Southern industries.

The first power delivered was in 1905 and up to 1906 the peak load was 800 kilowatts—all generated from the Catawba Station. The present capacity of this great system, including sixteen generating stations, is over 600,000 kv-a.

Located in one of the chief centers of the cotton belt, the Southern Power Company serves one-eighth of the cotton spindles of the United States. (Each small dot on the map above represents 10,000 spindles installed in textile plants.) There are 2,500 miles of power lines on the system, which is insulated for 100,000 volts. The view shown above is near the Fishing Creek Plant (shown in the foreground). A short distance south of this point are two of the main distributing stations—Dearborn and Great Falls. One of the largest and perhaps the earliest outdoor switching equipment ever installed is located here, as well as some of the largest transformers in the world.

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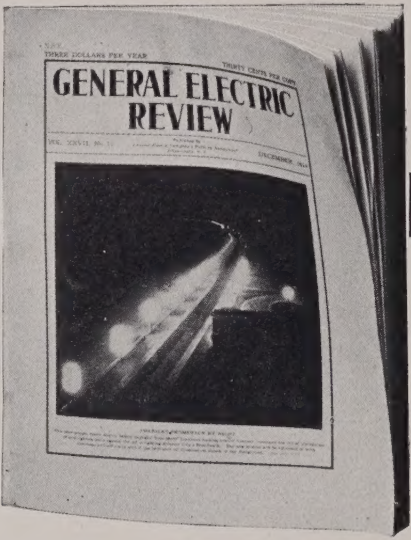

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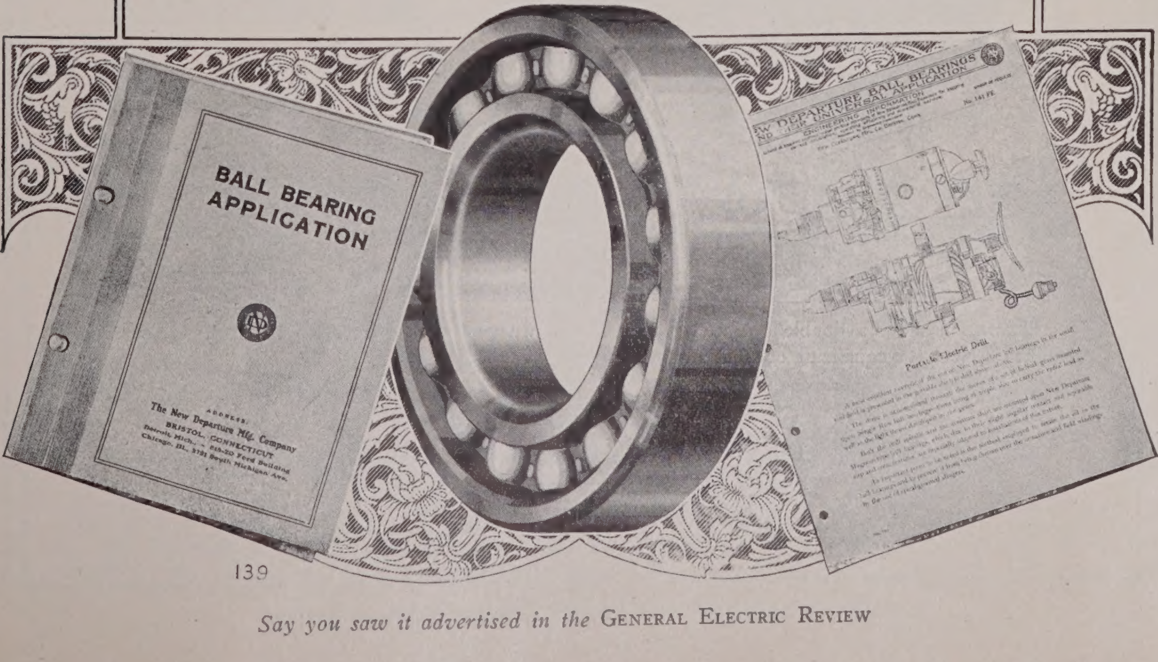

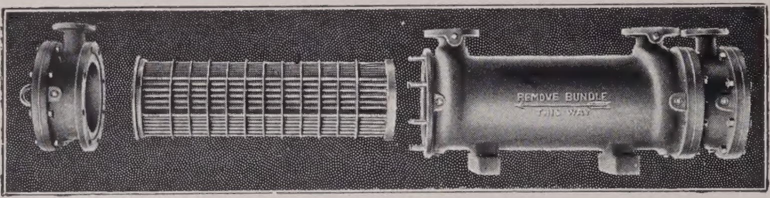

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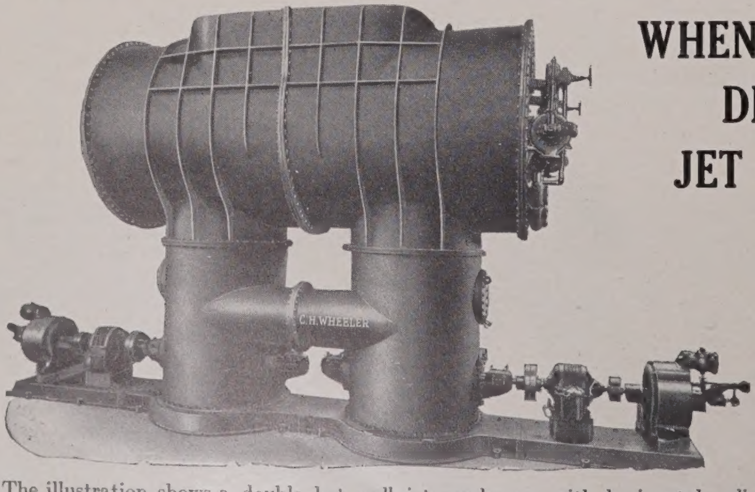

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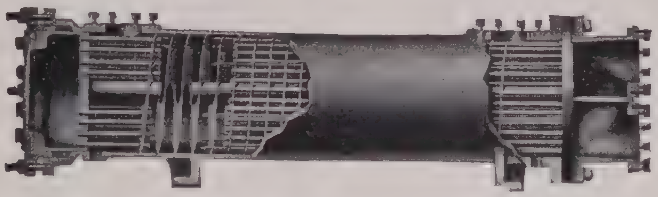

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are the accepted standard among engineers for insulation resistance tests of generators, motors, transformers, insulators, cables, wiring and other electrical apparatus, at installation and for general maintenance.

Instruments are available which read directly as low as 5 ohms and as high as 10,000 megohms

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10,000 volts search out the "spots"

You can now get insulation with every square inch "tested"

Sheets of Diamond Fibre Insulation are passed between electrodes carrying a current up to 10,000 volts, depending on the thickness of the material. Wherever a "spot" occurs, the material is burned through.

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N5

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Each turbine develops 22,000 H.P. at 171.4 Rev. under 150 ft. head and is direct-connected to a 12,500 kw. General Electric Generator.

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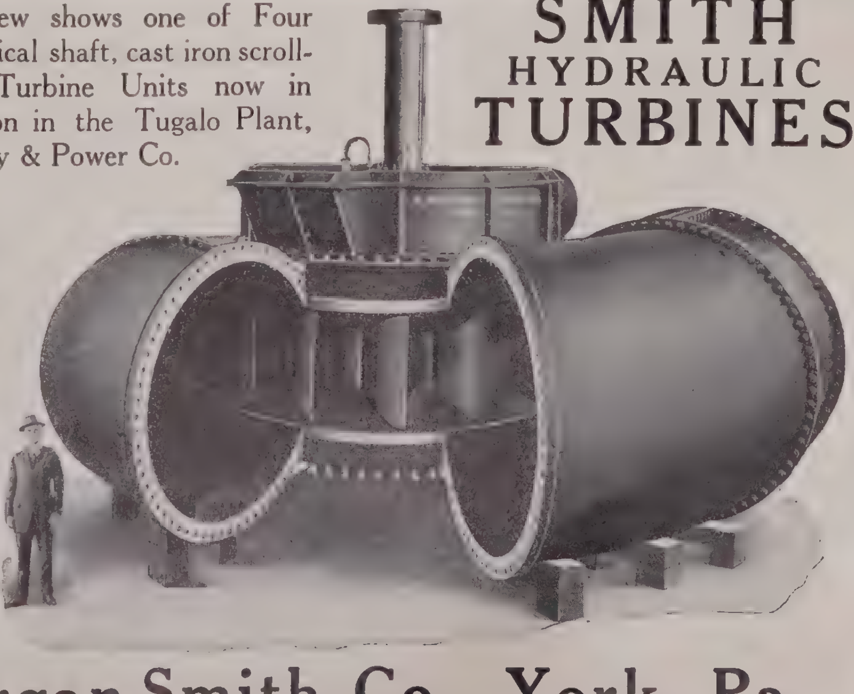

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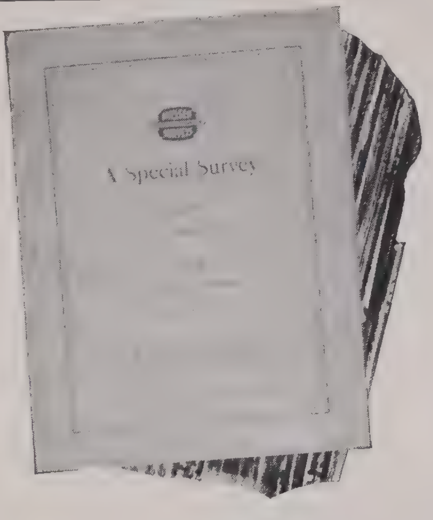

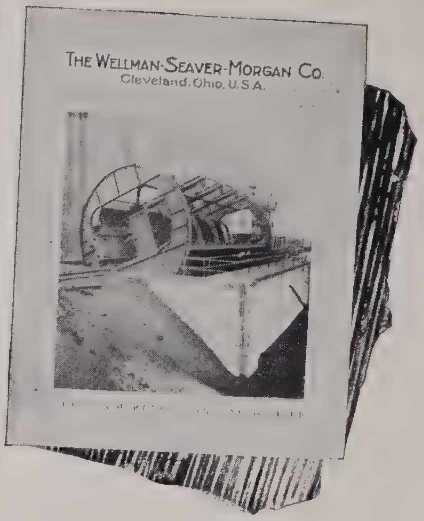

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By the use of the W-S-M Revolving Car Dumper!

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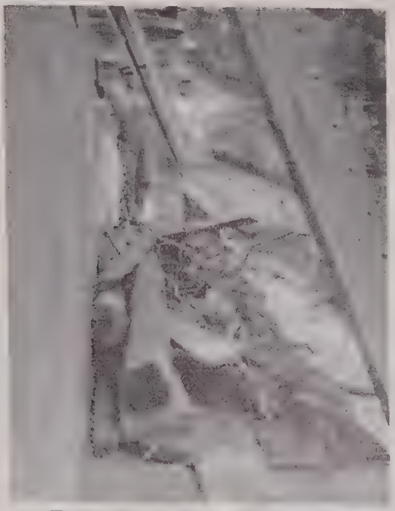

Typical load of trash hoisted by Newport News Rack Rake

Floating and submerged debris reduce power output and is expensive to remove *by the usual hand-raking method.*

NEWPORT NEWS RACK RAKE installation insures clean rack surfaces, at lowest cost of operation.

Now is the time to prepare for removing trash brought down by spring freshets.

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And the price? When the first two are considered, the price of Buffalo equipment will always prove to be the lowest. This is one of the reasons for the use of our fans in some of the largest stations.

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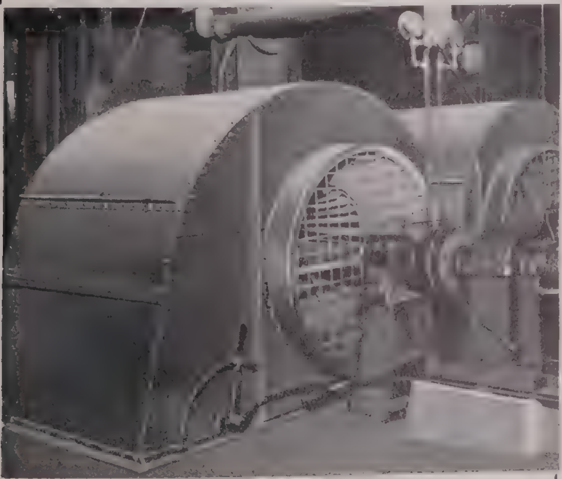


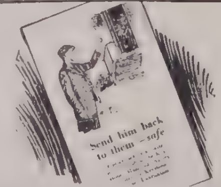
What I Know
About
Multiple Feed High Pressure Lubrication

By a master mechanic

It is a matter of constant surprise to me, that in so many manufacturing plants so little attention is given to the solution of problems connected with lubrication. In a large number of cases the same methods are in use today as were followed fifty years ago. Although new methods of improved lubrication have been brought forward, perfected, and although these have been successful in eliminating accidents and adding plant efficiency wherever used, it is a shocking fact that in so many big establishments the old-fashioned, antiquated oil-can is still the mainstay of lubrication. The only explanation of this condition is the existence of the "if it was good enough for father it's good enough for me" spirit. And this despite the large number of mishaps to men engaged in oiling by the old-fashioned methods and the number of fires, some of them quite costly, which result from the spattering of lubricants.

Accidents to "Oilers"

Considering the matter merely from the standpoint of accidents to oilers, statistics tell an impressive story. Companies writing compensation insurance in Pennsylvania, covering all kinds of industries over a period of years, have compiled figures showing that out of 1,542,349 compensation days lost as a result of accidents, 104,971—or nearly 7 per cent—were due to injuries to workmen while oiling or cleaning machinery. (*Continued in our free booklet "Send him back to them—safe." Read the complete story.*)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B T-H

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- Finger bar of insulated steel.
- Pivoted type fingers.
- Renewable finger tips.
- Easily removable arc deflector plates.

For A-C. and D-C. Motors

Photograph of typical crane controller with arc deflectors open showing construction.

The British-Thomson Houston Co., Ltd.
Electrical Engineers and Manufacturers
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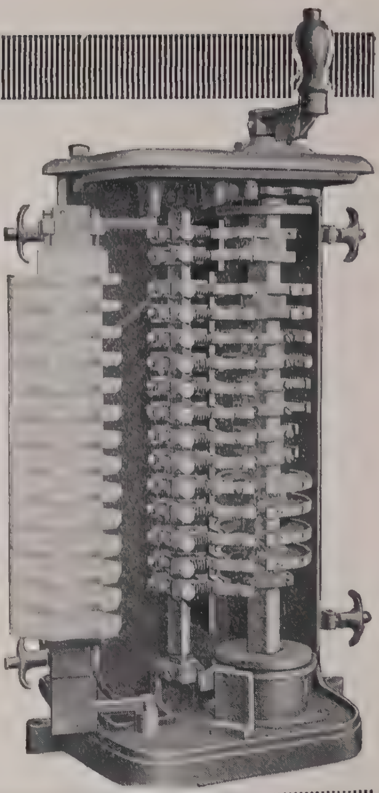

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Vol. XXVIII, No. 2

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FEBRUARY, 1925

CONTENTS

PAGE

Frontispiece: Coal Discharging Tower at the Hudson Avenue Station of the Brooklyn Edison Company . . . 74

Editorial: Large Shovels with Long Handles . . . 75

Mechanical Features of the High-speed Coal Towers at the Brooklyn Edison Company's Hudson Avenue Station . . . 76
By C. D. BRAY

Generator Voltage Control for the High-speed Coal Towers at the Brooklyn Edison Company's Hudson Avenue Station . . . 80
By E. D. HARRINGTON

The Latest Type of Self-excited Generator for Arc Welding . . . 86
By H. R. MCKEAN

Percy Electric Dog and Taper Device for Saw Mill Carriages . . . 91
By J. J. TALLMAN and C. A. BINNS

Control Equipment for Motor and Trail Cars on the Java State Rys., Dutch East Indies 95
By FRANK GUILLOT

Luminescence or Cold Light . . . 103
By W. S. ANDREWS

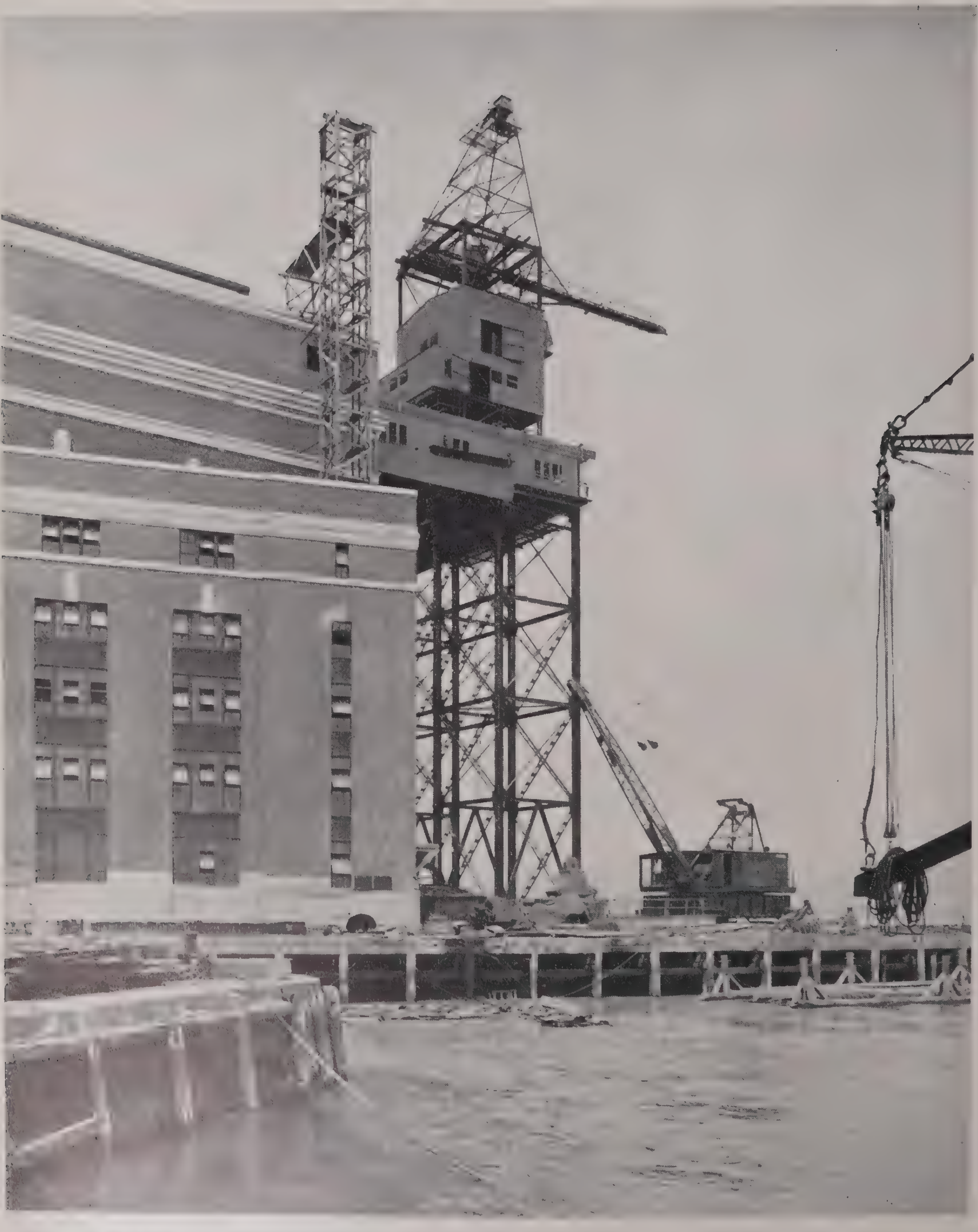
Elevator Operation with Alternating-current Power Supply . . . 109
By C. C. CLYMER

Recent Developments in High-frequency Inductive Heating . . . 121
By DUDLEY WILLCOX

Exciter Field Rheostats . . . 125
By J. F. FORMANEK

Study of Crystal Structure and Its Applications. Part III . . . 129
By W. P. DAVEY

Library Section . . . 138



WHERE COAL IS UNLOADED AT THE BROOKLYN EDISON'S HUDSON AVENUE STATION
The grab bucket [illegible] coal from the barge, lifts it 200 ft., trolleys it in, and discharges it into the hopper, returning empty. The tower is one of two, each rated at 250 tons per hour, requiring a complete cycle of operations every 36 seconds, with a [illegible] 1460 ft. per min. Initial tests showed the tower easily_able to unload 300 tons per hour

GENERAL ELECTRIC REVIEW

LARGE SHOVELS WITH LONG HANDLES

At the side of a building some 200 ft. high, two giants are shovelling coal from a pile at their feet into one of the top-story windows. Their shovels are in keeping with their stature, and pick up 2½ tons at a scoop. With untiring regularity, Gog vies with Magog in making nearly two full strokes a minute; and the wagon-load shovelfuls disappear into the open window at the rate of 500 tons an hour. Stupendous workers, these supermen!

Just how stupendous we can best judge by attempting to equal their performance with laborers of ordinary human size. Kent, of Mechanical Handbook fame, gives figures which show, first of all, that 5 ft. 3 in. is an effective shovelling height. This means that each shovelful of coal would be relayed up a tier of 38 offset platforms to reach the 200-ft. elevation. The next step of the comparison introduces more startling numbers: a shovelling rate of 500 tons an hour would require nearly 200 coal heavers on each platform, making a total of 7500 at work. But this number would not be sufficient for continuous operation, because unlike the tireless giants our ordinary human laborer must be allowed time off in which to recuperate. Kent says the shoveller's daily output amounts to ten hours of continuous work at the above rate. For 24-hr. operation at least 18,000 men would be needed. The customary allowance of working days per man per year raises the number to 22,000. So far no supervision has been included. Were but one gang boss provided for each 25 laborers, the payroll would be increased to practically 23,000 men. This is the male population of a moderate-sized town to do the work of our two giants.

Who are these two giants, you ask? Two electrically-operated coal towers at the Hudson Avenue Station of the Brooklyn Edison Company. They have a capacity to unload and hoist all the coal that will be needed by this station when it develops the 400,000-kw. output for which it is ultimately planned.

Perhaps you have seen them while passing on a ferry boat. If you did, you probably gave them scant heed, so unostentatiously do they operate. On the other hand, how sharply you would have focused your attention had you seen in their place a tier of platforms studded against the building face and on them several thousand human beings with flashing shovels doing the same amount of work!

If your mind is one of those whose primary basis of measure is dollars and cents, you would have quickly and truly decided that the operation was enormously expensive. Figured at the wage scale of metropolitan coal heavers, this human beehive of industry would call for a daily expenditure of $100,000. The two electrically-operated, mechanical giants that you actually do see are working for a small fraction of what would be the cost of even *slave labor*, because slaves have to be provided by their owners with at least the bare necessaries for existence, which in this country today are far from cheap. So much for the reduction in operating costs brought about by developments in electrical and mechanical engineering.

If your mind is one of those which admires the doing of a big job with neatness and dispatch, look again at the coal towers as substitutes for an army of workmen. With mental gaze penetrate their sheet metal walls to the room in each tower where a single man controls every movement of the operation. By a system of generator-voltage control, applied here for the first time to high-speed coal towers, the operator is enabled to make his machine perform with an exceptional degree of nicety. This results in better operation and lower maintenance. The maintenance cost of the electrical control equipment is particularly low because only a small current is handled, that of a generator field. For the same reason, this system advances the capacity of control apparatus for such towers beyond the limits of rheostatic or other systems that handle the full power current directly.

These are but a few of the more distinguishing features of the towers, not visible to an observer on a ferry boat, and with other mechanical and electrical features are fully described by C. D. Bray and E. D. Harrington in the following pages.

Mechanical Features of the High-speed Coal Towers at the Brooklyn Edison Company's Hudson Avenue Station

By C. D. Bray

New York Manager, Mead-Morrison Manufacturing Company

The universal use of electricity in large cities has brought into being the huge modern steam generating plant or central station. The steady output of hundreds of thousands of kilowatts demands an equally steady inflow of large quantities of coal to the station. Problems of rapid handling of this coal have usually been met by installing some form of steam crane or hoist. We come now to an electrically-driven coal tower which is capable of exceptional unloading and handling speeds but which can nevertheless be operated with ease by one man. The article by Mr. Bray deals with the mechanical features of the towers, and is presented in conjunction with an article by Mr. Harrington on their electrical features, appearing on page 80 of this issue.—Editor.

The modern coal discharging tower is an evolution from the early crude method of hoisting coal in hand filled tubs on a swinging boom with horses for motive power. This has come about as the result of higher costs, increased size of carriers, demurrage, and other economic factors that from time to time have made necessary greater heights and capacities of hoist together with other important modifications and improvements.

The immense growth in size and capacity of the individual power generating station, with its unprecedented efficiency that enables power to be sold over wide areas at a comparatively low charge, requires the handling of an enormous quantity of fuel at high speed and low cost. This scale of operation has during the past ten years introduced problems that could be solved only by radical departures from the old methods. Throughout this period of development the progress in design and construction has been accomplished by improving features that were found to be successful and eliminating those that proved to be undesirable. This latter work was responsible for a considerable share of the advance.

The coal towers of the Brooklyn Edison Company at Hudson Avenue are an outstanding example of what painstaking determination of general design and construction, and careful selection of mechanical and electrical equipment, will do to produce a coal handling plant ideally fitted to meet existing conditions, particularly with regard to simplicity, low maintenance and operating cost, dependability, smooth and accurate bucket control, and a comparatively high capacity, together with the elimination of certain disadvantages inherent in previous installations. For example, the adoption of generator-voltage control and of the particular type of mechanical units for this installation has been fully justified by subsequent performance.

The electrical features of this installation are treated in a separate article in this issue,(1) and the present description will therefore be confined largely to the mechanical features.

The unloading unit, of which there are two, consists essentially of a structural steel tower which is provided with a horizontal boom extending out from the coal dock and which has a receiving hopper built into the framework at the face. The main hoisting machinery is located at approximately the level of the receiving hopper, and is protected by a housing. The operator is located in a cab on the water side of the tower. Each tower structure is mounted on wheels, for moving along the trackway from place to place, and is operated independently. Experience has demonstrated that a straight in-and-out motion of the grab bucket embodies material advantages over a swinging boom or revolving type of unloading rig. The grab bucket is carried on a single whip, hoisting at a rope speed of about 1460 feet per minute. The size of the vessels discharged at this plant limits the capacity of the grab bucket to something less than three tons, and this fact, together with the height of lift, precludes the use of a bucket carried in the bight of the line if the required handling capacity of 250 tons per hour is to be realized. The type of tower installed permits only the minimum deflection of hoisting cables over the sheaves and consequently results in low maintenance cost.

The vertical movement and the opening and closing of the grab bucket are controlled by an electric twin-drum hoist machine and the horizontal movements by an electric single-drum trolley machine. The hoist machine (Fig. 1) consists basically of two drums mounted loosely on a shaft on either side of a central keyed friction member provided with heat-radiating ribs. Each drum has a conical end surface faced with asbestos friction material which engages a companion internal conical surface of the central member. The drums are moved along on the shaft independently, and thrust into engagement with the friction member by application of air through an equalizing ball-bearing thrust yoke. They are disengaged by coil springs upon exhausting the air from the cylinder. The design is such that these operations create internal shaft stresses only, and do not bring additional load on the main bearings. The drum bushings are made in halves, and they, together with the friction surfaces and thrust yokes, may be renewed without disturbing the shaft in its bearings. The main shaft is carried in pedestals mounted on a structural frame which is extended to permit the integral mounting of the motor. The motor is direct-coupled to the drum shaft through a special slip coupling with pins in bushings, which compensates for end motion of the armature shaft. An extremely sensitive and flexible frictional drive is obtained through the use of compressed air, as this enables the drums to be engaged or disengaged smoothly while the motor is rotating. One drum operates the hoisting, lowering, and holding of the grab bucket, and the other its opening and closing motions. The holding drum is equipped with an asbestos lined band brake, spring applied and air released. Air is admitted and exhausted from the brake-operating air cylinder through the agency of a pilot valve operated by a cam on the hoist master controller. The contour of this cam provides the graduated intensity of brake application required for the lowering and final checking movements and for the closing period of the grab bucket. This brake automatically sustains the load, except when released, and is electrically interlocked so that it will be reapplied automatically, and will check and sustain the grab bucket in case of power failure, or when the speed, voltage or field conditions of the electrical equipment are such that the grab bucket might otherwise be out of control.

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(1) See page [illegible]

The grab bucket is suspended from the trolley carriage, which in turn is moved along the boom by the trolley machine, as shown in Fig. 2. Outward travel is accomplished under power, inward travel by the horizontal component of the weight of the load against mechanical as well as dynamic braking action. The trolley machine consists of a single drum driven by an electric motor through one helical spur gear reduction. A band brake on the motor shaft automatically prevents counter-rotation unless released by air application. Upon forward rotation of the machine this brake automatically releases. The drum is driven through slip friction surfaces adjusted for holding the maximum rope pull under working conditions. A safety release feature is thus provided which will prevent damage to the structure and mechanism should the operator through an error in judgment attempt to run the trolley beyond the end of the boom.

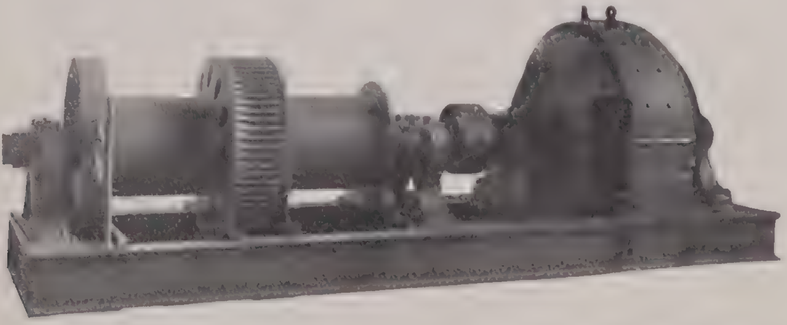
Fig. 1. Electric Hoist Machine, Showing Rope Drums and Air-cooled Cone Clutches

A single operator controls all movements of the grab bucket through a system of levers mounted on a stand. He is provided with a motorcycle seat before the stand, and his position is such that he has a commanding view of all operations of the bucket.

The hoist master controller is actuated by foot pedals, one for hoisting and the other for lowering with regenerative braking. A cam on the master controller actuates an air pilot valve for exhausting or admitting air to the holding-drum brake cylinder, releasing and applying the brake to the predetermined degree required during each of the various periods of the bucket cycle.

The hoist-machine drums are frictionally engaged and disengaged by air cylinders mounted on each end frame of the hoist machine. The air supply is controlled through separate pilot valves actuated by short hand-levers and connections. Each hand-lever is furnished with a squeeze latch, mechanically interlocked through a lever system to a trolley master switch mounted on the control stand. The right-hand lever operates one master switch for outward travel under power, the left-hand the other master switch for inward travel under dynamic braking, and simultaneously supplies air to release the trolley-machine brake, allowing the bucket to come in and overhaul the drum.

The grab bucket is of a type specially developed for coal discharging towers. Two shells, each constituting one-half the bowl, are hinged to the bottom head, and to links connecting to the top head. The holding cable for sustaining the bucket is attached to the top head, and closing is accomplished by a crane chain attached to the opening and closing cable having a six-fold purchase rove over sheaves in the top and bottom heads. The chain is provided with a stop which limits the bucket to full open, the weight of the top head serving to open the grab when the closing cable is slacked off from the drum. An automatic guy, or tag line, is installed to prevent the grab bucket from twisting upon being hoisted and lowered.

The entire tower structure is mounted on sixteen 24-in. diameter chilled-steel wheels, ground to a uniform circumference, arranged in groups of four under each tower leg. All wheels are carried in structural steel trucks, pin connected, in a manner to equalize the loads fully at each corner of the tower upon all of the supporting wheels. Two wheels in each group are provided with worm gears on the extended axles, engaging with worms, and suitably connected through shafting, mitre and spur gears, to a single motor for propulsion in either direction along the trackway at a speed of about 50 feet per minute. A solenoid brake on the propelling motor, together with the inherent irreversibility of the worm gearing, effectually locks the wheels except when moving under power.

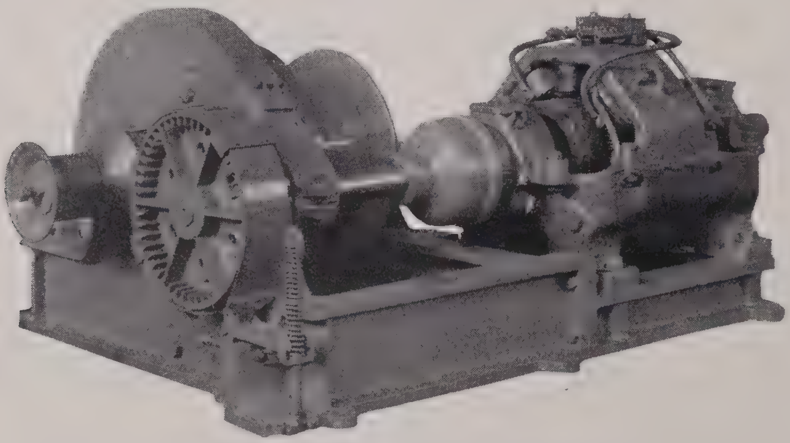

Fig. 2. Motor-driven Trolley Machine for Moving the Grab Bucket Horizontally

As an additional precaution against drifting of the tower, a powerful automatic rail clamp is located on either sill. The clamp carries a weight on a lever pivotally connected to a toggle. The weight serves to rotate the lever, set the toggle, and place the jaws in a position to seize the rail through eccentric self-tightening manganese-steel cams. A tendency of the tower to move further tightens the clamp, as the short radius of the cam is initially presented to the rail. For releasing, the lever arms are rotated in the opposite direction by an independent motor-operated single drum machine. The machine consists basically of a drum connected through suitable gear reduction to the motor and mounted integrally on a cast-iron frame. The ropes from the lever arms of the clamps are led to the drum by an arrangement of guide sheaves.

When power is applied to the tower propelling motor, the first operation is to release the clamps by supplying current to the independent clamp-operating machine. An electric interlock is provided so that the rail clamps must be in the fully released position before the tower can be started along the rails. A limit switch and magnetic solenoid brake are so mounted on the machine that when all the lever arms are fully raised the current is automatically cut off from the motor and the lever arms sustained in the released position. As soon as current is cut off from the tower propelling motor the solenoid is de-energized, the brake is released, the lever arms rotate, and the clamps engage the rails. The control circuit is interconnected with the circuit of the tower propelling motor, so that if the current supply fails while the tower is being propelled, the solenoid brake of the propelling motor will operate to check the travel of the tower, and the rail clamp applying weights will descend under the action of a governor-applied brake, which affords a time interval between the setting of the solenoid brake on the tower propelling motor and the application of the rail clamps. Contact switches are provided on each clamp which complete a circuit only when all clamps are in the applied position. The operator has only to press a push-button in this circuit to ascertain that all clamps are properly set, as indicated by an electric lamp.

The coal is discharged from the grab bucket into the tower receiving hopper, which is provided with a bar screen to bypass the slack. From the hopper a chute leads to a duplex single-roll coal crusher. A composite roll is used, made up of manganese-steel segments mounted on cast-iron spiders. The crushing is accomplished between the revolving rolls and pivoted baffles or breaker plates, held to their work by means of spring-hung counterweights. Both rolls and baffles are provided with manganese teeth. The pivoted construction of the baffles allows foreign material to pass through the crusher without damaging it. The rolls are geared to a countershaft provided with a motor-driven pulley.

Below the crusher there is an equalizing hopper which terminates in two openings directly above the trackway of the distributing car system. These openings are provided with gates of the duplex undercut type, the opening and closing being accomplished by an electric motor through suitable gear reduction, crank shaft, and connecting rods. The motor is provided with a solenoid brake to bring the moving parts to rest, enabling the attendant to register accurately any degree of opening. A limit switch is included to bring the gate jaws to rest at the full closed position. A slip-friction unit is interposed at the gear reduction to prevent damage to the gate in the event of foreign material becoming lodged between the jaws.

The coal handling towers were designed and constructed by the Mead-Morrison Manufacturing Company and all electrical equipment was furnished by the General Electric Company.

Electricity Also Performs Record Service in Hoisting Coal to the Earth's Surface

A new world's record for hoisting coal from a single shaft in one shift was recently set by an electric hoist owned by the Valier Coal Company at Valier, Ill. The output of this hoist in seven hours and fifty-one minutes was 8664 tons of coal. The previous record was held by the Orient No. 1 mine of the Chicago, Willmington and Franklin Coal Company, where a steam hoist in eight hours lifted approximately 8300 tons of coal.

The electric hoist at Valier is of the skip type and is driven by a direct-current motor of 1350 h.p. at 55 r.p.m. The power supply is furnished through a motor-generator consisting of an 1100-h.p. induction motor and a 1000-kw. generator operating at 720 r.p.m. The flywheel of the set weighs 31,000 lb.

The shaft in which this record performance was made is 672 ft. deep.

Generator Voltage Control for the High-speed Coal Towers at the Brooklyn Edison Company's Hudson Avenue Station

By E. D. Harrington

Industrial Engineering Department, General Electric Company

The use of electric drive in coal unloading and distributing towers for central stations opened up a new field of industrial electrical applications. The demands of this application were for motors having special acceleration and torque characteristics, as well as simplicity of operation and ease of control. To meet all of these requirements, the generator voltage control system has been employed with exceptionally satisfactory results. Mr. Harrington discusses in detail the features of this system in its special application to the high-speed coal tower. His article and that of Mr. Bray on page 76 together give a complete description of the interesting installation at the Brooklyn Edison Company's plant.—Editor.

The typical large steam power station of today is necessarily equipped with mechanical means for unloading vast amounts of incoming coal and for hoisting it from the railway siding or water level to an appreciable height for storage. From here it can flow, partly by gravity, through various crushing, weighing, and distributing devices, to hoppers and thence to the boiler stokers. In many cases it becomes desirable to combine this unloading and elevating movement into one operation.

After this handling outgrew the capacity of manual and animal labor, the work was done largely by the steam-operated coal tower, consisting essentially of a steam winch unloading and hoisting the coal in a "grab" or clam-shell bucket.

When the height of hoist, hoisting speed, and hourly tonnage all began to increase, and when greater recognition was given to operating and maintenance expenses, continuity of service, and flexibility of control, the electrically-operated coal tower began to receive consideration. Today, the latest development in electric coal towers, having passed through various stages of successful design and construction, finds exemplification in two towers recently installed at the Hudson Avenue Station of the Brooklyn Edison Company. (See Figs. 1 and 2.)

THE NEW TOWERS

The hoisting motors of these towers for the first time embody "Ward Leonard," or generator voltage control, adapted to meet the special requirements of this particular service. By means of this system, the speed and direction of rotation of the hoist motor is entirely controlled by the strength and polarity, respectively, of the driving generator field. Furthermore, by proper manipulation of the generator field, the hoist motor will lower and retard the bucket very nearly to a standstill, by means of regenerative braking. This lowering and retarding pumps power back into the line, leaving to the mechanical brakes the comparatively light duty of holding the load at rest.

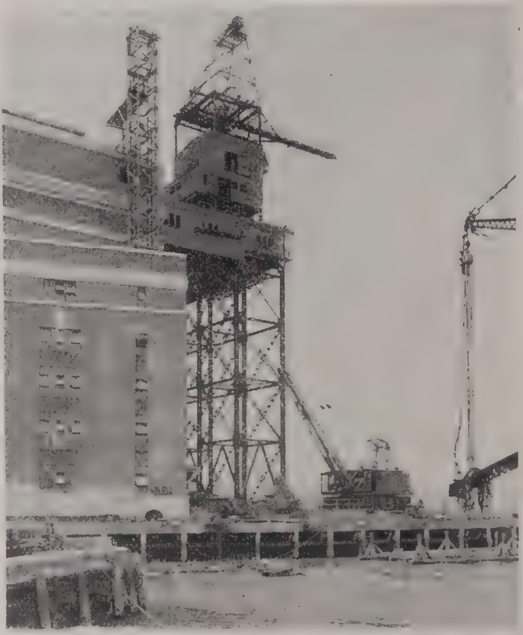

Fig. 1. One of the Electric Coal Handling Towers Built for the Brooklyn Edison Company. The towers travel on tracks supported by the trestlework, so as to register over any point of the discharging wharf

Mechanical Operation

Fundamentally, a coal tower provides three motions: first, a closing and opening motion of the bucket; second, a "hoist" or vertical motion of the bucket; and third, a "trolley" or in-and-out motion of the bucket.

Fig. 3 shows in simplified form the roping of a modern high-speed coal tower similar to that installed for the Brooklyn Edison Company. A single motor is used for both closing and hoisting motions.

The grab bucket, which consists of two leaves *BB*, is hoisted and lowered on rope *H* and closed and opened by rope *C*. When suspended on rope *H* with rope *C* slack, the leaves *BB* are so counterweighted that they spread apart as shown. In this position the bucket is lowered onto the coal pile. Clutch *HC* is now released, and drum *HD* remains at rest while the hoist motor *HM* rotates drum *CD*. Rope *C* is thus pulled in, bringing the leaves of the bucket together and picking up a load of coal. Just as leaves *BB* come together, drum *HD* is again clutched to the motor shaft and the continued rotation of motor *HM* hoists the loaded bucket by bringing ropes *H* and *C* up together.

As the top of the hoist is reached, the motor is stopped and held with a brake on drum *HD*, thus suspending the full bucket in the air. At the same time, the brake holding trolley drum *TD* is released, and the trolley carriage with the full bucket is brought in over the hopper by gravity. To discharge the bucket, motor *HM* is reversed with clutch *HC* released, thus paying out on line *C*, and with the bucket suspended on line *H* from the locked drum *HD*, the leaves *BB* separate and drop the coal in the hopper. The open bucket is then trolleyed out and lowered again to the coal pile at the loading level.

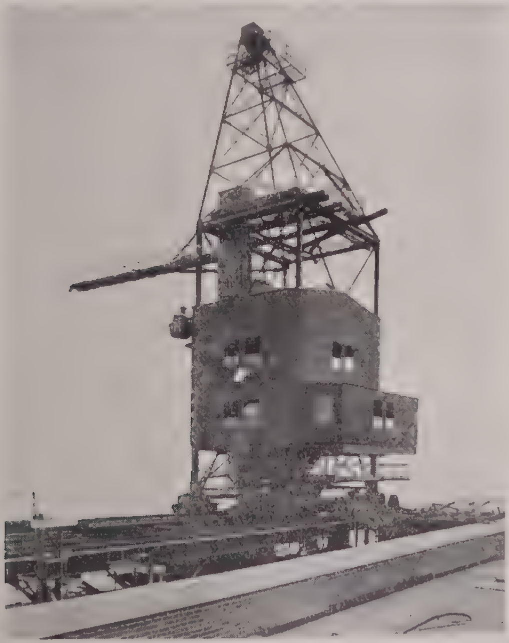

Fig. 2. Coal Tower from the Central Station Roof. The housed portion contains all of the d-c. generating equipment as well as motors and hoist machines

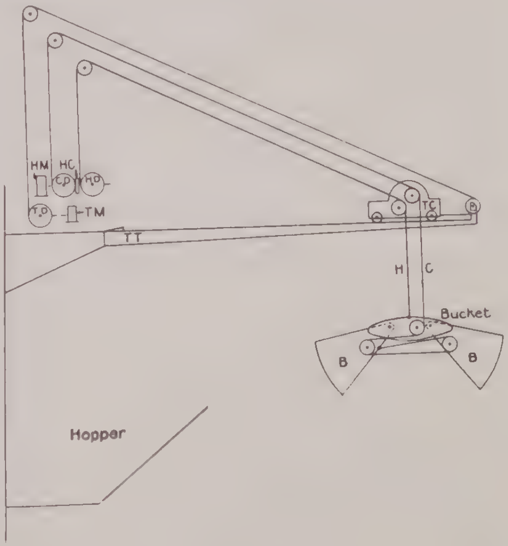

Fig. 3. Cabling Scheme of the Grab Bucket. By holding fast ropes H and C, the bucket is trolleyed in by the horizontal component of gravity

The apparatus for the hoist and trolley motions is mounted in a traveling tower which carries the trolley boom *TT* properly supported and projecting outward over the coal which it is required to handle. The tower runs on a track supported on a trestle which borders the water front or railway siding at which the coal is delivered. In addition to the "hoist" and "trolley" equipment, the tower is electrically propelled along the trestle rails and usually carries electrically-operated rail clamps, crusher- and hopper-gates. Power is collected from trolley wires or under-running collector rails.

Before proceeding to a detailed description of the Hudson Avenue Station coal towers, it will be well to consider the advantages of generator voltage control for this type of service.

Advantages of Generator Voltage Control

The most important of these advantages are as follows:

(1) The armature circuit between the hoist motor and driving generator remains closed at all times except in emergency, so that only field currents of comparatively low magnitude are

handled, thus making the control apparatus both small and simple. This results in a minimum of maintenance and repair expense and comparatively few outages, since the apparatus is readily understood and maintained by the operating electrician.

It should here be mentioned that, while generator voltage control requires an additional rotating unit in the shape of a motor-generator set, it is a step in advance to replace a complicated sequence of full-capacity contactors, relays and heavy current resistors, by a simple motor-generator set, the care and the operation of which are well understood by the average maintenance man.

(2) Great accuracy of speed control and stopping is provided, due to the low or "creeping" bucket-speeds which are possible. These low speeds are obtained with generator voltage control, both efficiently and with no reduction in the maximum torque available in the hoist motor.

(3) The known advantages of a high-voltage alternating-current incoming power line and of a low-voltage direct-current hoist motor are obtained, with few of the disadvantages of either.

(4) Since the rate of acceleration is largely determined by the rate of rise of generator voltage, and since it is impossible to secure abrupt increments of generator voltage, due to the high inductance of the generator field circuit, the acceleration and retardation become exceedingly smooth and free from sudden torque changes of the hoist motor. Thus high rates of acceleration and retardation are practicable without undue cable wear or excessive strain on the mechanical members of the tower.

(5) Retardation to very nearly a stand-still is obtained by electrical regenerative braking, which practically eliminates wear on the mechanical brake.

(6) The maximum torque of the hoist motor is largely a function of armature current and, therefore, full rope pull is available even with severe voltage fluctuation of the incoming power.

(7) The foregoing advantages go a long way toward the assurance that the coal tower will be fast, reliable and generally successful. In addition to these advantages, generator voltage control shows a comparatively low maximum kv-a. demand as well as a saving in power consumption. This is due in large part to the absence of rheostatic losses when accelerating and retarding and to the regeneration of power when retarding as well as when lowering the bucket. Since the total power consumed by the complete tower is largely made up of that consumed by the hoist motor, the saving in cost of power is appreciable.

The Hudson Avenue Station was laid out for an ultimate capacity of 400,000 kw. The present installed capacity consists of three 50,000-kw. turbine generators.

The coal towers installed at this station, as before mentioned, were designed to hoist a bucket loaded with 5000 pounds of coal at a speed of 1460 feet per minute. The total height of hoist above mean tide level is 200 ft., and the rated capacity is 250 tons per hour. This performance means that the bucket must pick up two and one-half tons of coal at tide level, hoist it vertically 200 ft., trolley it in over the receiving hopper, dump it, trolley out empty and lower back to the boat in 36 seconds. The first of these towers went into service in May, 1924, and the indications are that the rated output will be appreciably exceeded. For example, on the second day the tower was in service, a good operator readily handled coal at a rate of over 300 tons per hour. When the tower is well worked in and the stiffness eliminated from mechanical parts, and when the operator is so accustomed to the generator voltage control that he may take full advantage of its time saving possibilities, the normal capacity of the tower will probably prove to be considerably in excess of its rating of 250 tons per hour.

ELECTRICAL EQUIPMENT

For purposes of discussion, the electrical features of this coal tower may be divided into four major parts; namely, (A) hoist motion, (B) trolley motion, (C) tower-propelling motion, and (D) auxiliaries. These various divisions will now be discussed separately:

(*A*) The hoist motion, which loads, hoists, dumps and lowers the bucket, is operated essentially by a motor-generator set, a hoist motor, and the necessary switching and control assemblies.

The prime mover of the motor-generator set shown in Fig. 4 is a 700-h.p., 3-phase, 60-cycle cage-wound induction motor, taking power from 2300-volt collector rails which feed through an incoming line panel and a starting and running panel to the induction motor, with the necessary metering and protective devices.

To this induction motor is direct-connected the 500-kw., 275-volt shunt-wound main generator which drives the hoist motor, and also a 75-kw., 250-volt compound-wound auxiliary generator operated at substantially constant voltage to drive the trolley motor and to furnish separate excitation for the main generator, hoist motor fields and control circuits.

Primary switching and protective equipment is provided for the main and auxiliary generators, together with a 75-kv-a., 2300/460-volt, 3-phase, oil cooled power transformer with distribution switchboard for supplying low voltage alternating current power to the propelling motor and auxiliaries.

The hoist motor shown in Fig. 5 is rated at 625 h.p., 275 volts, 180 r.p.m. This motor is shunt wound, is of the forced ventilated type in order to reduce the WR^2 of the armature, and is direct connected to the holding- and closing-drum clutches without gearing.

Hoist Control

The control (see Fig. 6) of the hoist motor is of the generator voltage type, as previously mentioned, and is embodied in a control panel mounting the necessary contactors and relays which are in turn operated from a master switch in the operator's cab, overlooking the line of hoist.

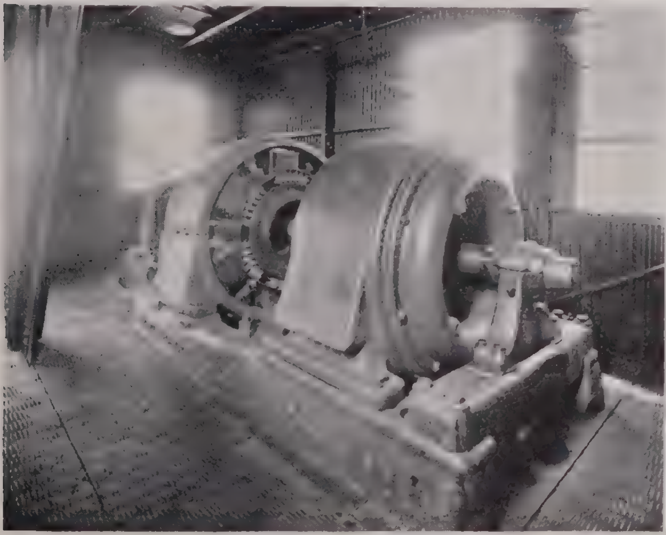

Fig. 4. The Main 500-kw. Motor-generator Set is Mounted Inside the Tower. The 75-kw. generator for excitation and trolley-motor supply is shown in the background

The control provides regular and special features as follows:

(1) The hoist motor is reversed by changing the direction of the generator field.

(2) Automatic acceleration is obtained by a combination of the inherent time lag of the generator field and the voltage-limit method.

(3) A means is provided for accelerating the hoist motor to full speed at an approximately constant rate of acceleration. This eliminates the comparatively long period of time necessary to secure the last part of the motor acceleration, due to the inherent dragging out of the speed-time curve of a motor controlled by a fundamental and unmodified generator-voltage system. Furthermore, this advantage is obtained with no increase in the commutating duty on the generator or hoist motor.

(4) The hoist motor field is over-excited during the accelerating period, in order to compensate for the drop in excitation voltage at this time and to assure maximum torque per ampere from the hoist motor.

(5) The rate of retardation is so controlled that it will automatically adapt itself to the different duties of retarding a full hoisting bucket and an empty lowering bucket.

(6) Discharge and neutralizing circuits are provided for the generator field.

(7) Hoisting and lowering speeds may be independently adjusted. This permits of a certain increase in hourly tonnage if desired, since it is practicable to lower an empty bucket at a speed considerably higher than that possible for hoisting it loaded, and still maintain adequate control of the bucket.

(8) Automatic provision is made for a lower rate of acceleration in lowering than in hoisting, in order to insure that slack will not be paid out in the closing line, during this latter period.

(9) The necessary protection is provided in case the hoist motor is "plugged" from forward to reverse or vice versa.

(10) In case of power failure, under which condition the bucket might tend to run away, automatic provision is made for de-energizing the hoist motor, and applying both mechanical and emergency dynamic braking. This action may also be initiated by tripping an emergency switch, located convenient to the operator's hand.

(11) The control is so interlocked that it is impossible to energize the hoist motor and release the mechanical brakes until the motor-generator set is running at approximately the correct speed, the main direct-current circuit-breaker closed, auxiliary generator voltage built up, the proper hoist motor field established, and the blower for the hoist motor operating. The failure of any of the above conditions will automatically de-energize the hoist motor and apply dynamic and mechanical braking.

(***B***) The trolley motion which propels the bucket in from a point above the coal supply to the dumping position over the receiving hopper, and return, is driven by a 75-h.p., 485-r.p.m., 250-volt series motor (Fig. 7), taking power from the auxiliary generator on the motor-generator set. The hoist and closing drums and clutch may be seen in the background of this picture.

Trolley Control

The control for this motor (Fig. 8) is of the rheostatic type and embodies in a panel mounting the necessary contactors, relays and resistors under the control of a master switch in the operator's cab. Two points of speed control are provided in both directions with dynamic braking in the "trolley in" direction.

The trolley carriage is roped to the trolley motor (see Fig. 3) in such a way that very little power is required to move it when it is in over the hopper. However, as the carriage moves outward along the boom, a gradually

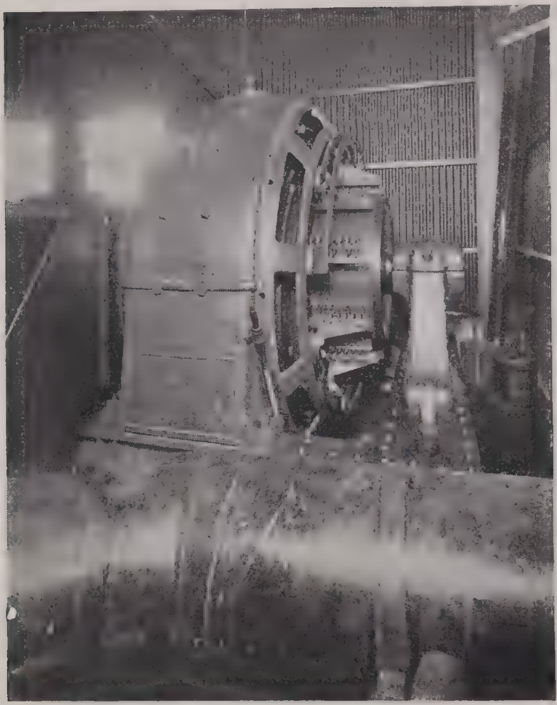

Fig. 5. The 625-h.p. Motor which is Direct-Connected to the Main Hoisting and Holding Drums

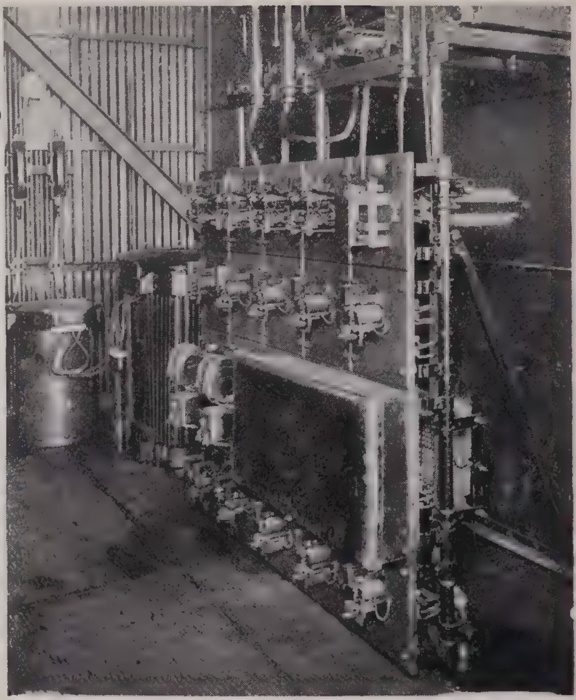

Fig. 6. Main Control Panel, Showing Relay and Contactor Equipment. This apparatus is manipulated by the main controller in the operator's cab

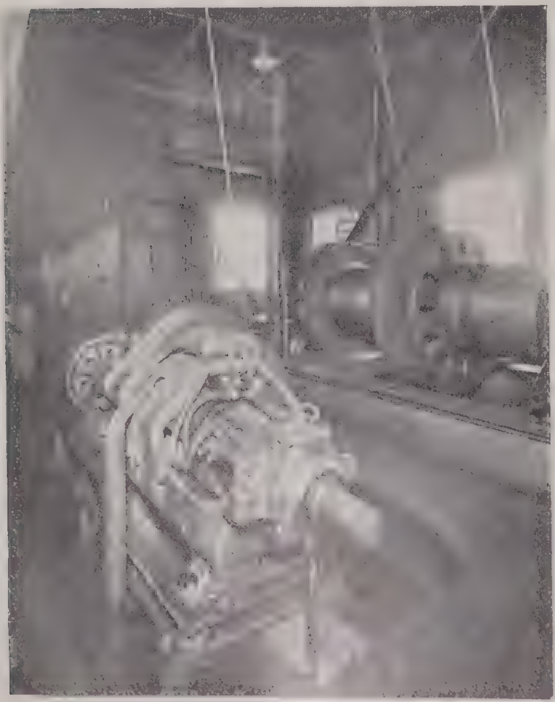

Fig. 7. View in Machine Room of the Coal Tower. The trolley motor appears in the foreground. Back of it is the main hoist machine with drums and clutches

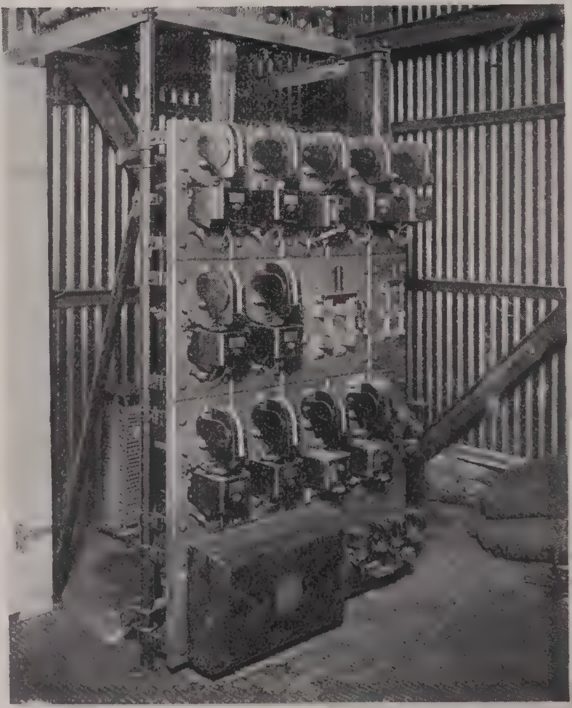

Fig. 8. Trolley Control Panel with Contactors for Providing Special Acceleration Characteristics When the Empty Bucket is Trolleying Out

increasing component of the bucket weight must be lifted, until at its extreme outward position, nearly the maximum torque of the motor is necessary to move the trolley carriage out. The control, therefore, is such that it automatically limits the torque peaks with the trolley carriage in over the hopper, and thus prevents an abnormally rapid acceleration at this point which would tend to throw the bucket out of control and draw it into the headwork. The limitation of torque at this point is obtained in such a way that the maximum torque of the trolley motor is still available in the outward position of the trolley carriage.

An air-operated mechanical brake is used on the trolley mechanism, primarily for holding the load.

(***C***) The propelling motion, which moves the tower along the top of the trestle on which it is mounted, is driven by a 60-h.p., 900-r.p.m., 440-volt wound-rotor induction motor mounted on the lower steel structure of the tower proper. The motor is geared to the driving wheels and receives power from the 2300/460-volt auxiliary power transformer. Sufficient torque is produced to move the tower against the heaviest wind that would be likely to blow in this location, with the rails in a rough condition and all running bearings stiff.

Propelling Motor Control

The control of the propelling motor is of the semi-automatic type with primary reversing contactors and with secondary resistance controlled directly on the drum controller. A solenoid brake is arranged to set when the propelling motor is in the "off" position and thus hold the tower from coasting. Furthermore, gravity-set rail clamps lock the tower to the rails in such a way as to prevent overturning or a running away in a strong wind. These rail clamps are released by a 3-h.p. torque motor, energized from a thumb button in the handle of the propelling controller. The control is so interlocked that the propelling motor can be energized only when the rail clamps are released and the tower is free to move. The propelling controller is located in the operator's cab in such a position that the operator may readily propel the tower and at the same time be in full view of the boat below; thus spotting the bucket accurately over the hatch.

(***D***) Certain auxiliary electrical apparatus is necessary for the complete and successful operation of the tower. As the coal is dumped from the bucket to the receiving hopper, it flows into a crusher driven by a 50-h.p., 720-r.p.m., 440-volt wound-rotor induction motor receiving power from the auxiliary power transformer. This crusher motor is provided with a speed-regulating hand controller having both overload and undervoltage protection. The crusher room is separated from the adjoining motor-generator room, by a dust-tight partition, in order to protect the motor-generator set and related switchboard equipment from coal dust.

From the crusher the coal flows to a receiver which feeds into the distributing system through motor-operated gates. Each of these gates is driven by a 3-h.p., wound-rotor induction motor receiving power from the auxiliary power transformer. Each gate motor operates through a reversing drum controller, having spring return to the "off" position. This permits overhead mounting of this controller with pull-ropes for each direction of gate travel extending below and convenient for operation. Limit switches are operated by the gate mechanism at the limits of travel and thus prevent overrunning.

A 2-h.p., squirrel-cage induction motor drives a centrifugal blower for force-ventilating the hoist motor. Four thousand cubic feet of air per minute at 2½-in. water pressure are used for this purpose, particular attention being paid to the air intake in order to prevent the entrance of coal dust or other foreign matter into the hoist motor.

A 50-cu-ft. air compressor, driven from the auxiliary transformer, supplies compressed air for the operation of the mechanical brakes on the hoist and trolley mechanism and for general maintenance purposes.

A 3-kv-a., 2300-230/115-volt single-phase transformer supplies the power for a floodlighting system sufficiently comprehensive to permit of night operation of the tower.

The design and construction of this electric coal tower installation was handled by the Mead-Morrison Manufacturing Company and all of the electrical equipment was furnished by the General Electric Company.

The Latest Type of Self-excited Generator for Arc Welding

By H. R. McKean

Industrial Engineering Department, General Electric Company

Direct-current generators for arc-welding service must have drooping voltage-current characteristics to provide for the lowered resistance of the welding circuit after the arc-current has been established. Unfortunately, inherent voltage regulation of this sort demands a very steady value of field excitation, consequently the differentially compounded generator cannot employ its own terminal voltage for excitation purposes. To avoid the cost and complication of separate excitation, a new form of generator having a split field has been devised. By using the armature reaction on this field, and installing a third brush, a constant voltage for self-excitation is obtained, thus making possible the necessary drooping voltage-current characteristic at the main brushes. Mr. McKean gives the exact theory of the new generator and points out its value in building a compact, inexpensive, portable arc-welding set.—Editor.

The phenomenal increase during the last few years in the use of the direct-current arc for welding has turned the attention of designing engineers to the problem of building machines specially adapted to this service.

Direct-current arc welding requires a considerably higher voltage for striking the arc than for maintaining it, and therefore a drooping voltage-current characteristic with perfect stability at low voltages and a not too great short-circuit current. In addition to these essentials, a simple and substantial construction of the apparatus and some method of current adjustment are of prime importance. Experience has demonstrated that voltage-current characteristics similar to either curves A or P in Fig. 1, or some compromise between them, are suitable for arc welding. These characteristics may be built into a generator in any one of several ways, so that the machine becomes an efficient and highly satisfactory source from which to supply power to a single welder.

Perhaps the best known method of obtaining inherent regulation in a generator is by the use of a compound field winding. A generator with a "heavy" series field connected differentially (i.e., to "buck" the main field flux) and with separately excited main fields will, with proper design, have good characteristics for arc welding. However, if the terminal voltage of a differentially compounded generator is used for excitation as in the ordinary shunt-wound generator, unstable conditions result, and the voltage-current characteristic takes the shape of curve M in Fig. 1. The machine then loses its value for arc welding service. This, together with the difficulty or impossibility of always obtaining a constant-potential source from which to excite the main fields of such a generator, necessitates including in the welding set a separate exciter with all its attendant troubles, complications and expense.

A less known but equally effective way of obtaining inherent regulation in a generator is by dividing each magnetic circuit into two paths placed at 90 electrical degrees from each other, and by utilizing the magnetizing effect of the armature coils ("armature reaction") to serve the same purpose as the series field winding on a differentially compound-wound generator.

Fig. 2 shows in simplified form the arrangement of a generator with armature wound for a two-pole field but with the field structure divided into four poles to form two magnetic paths at right angles to each other. Unlike direct-current generators of standard design the poles of this generator are not alternately of opposite polarity but are grouped in pairs of like polarity. The symmetrical arrangement of the pairs of poles allows the flux in either pair to be altered without affecting the other pair, since each pair of poles belonging to one magnetic circuit is located at points of equal magnetic potential with reference to the other magnetic circuit. This independent action of the fluxes is similar to that existing in a generator employing commutating poles placed between the main poles.

In order to understand the theory of this type of generator, assume that the flux distribution is as shown in Fig. 2, there being two fluxes at right angles, one of which, ϕ_M, will be designated the main flux and the other ,ϕ_C, the cross flux. The brushes are connected to points A and C in the neutral zones between poles of opposite polarity. Consequently, when the generator is loaded, the armature becomes a magnet with its axis in the direction OR. If the magnetomotive force (m.m.f.) of the armature be represented by the vector OR, it can be resolved into the components *OE* and *OD* along the axes of the poles. It will be seen that whereas *OE* opposes ϕ_C, *OD* tends to increase ϕ_M. Now in each pair of poles the member which carries the main flux, ϕ_M, has a restricted cross section so that saturation exists with normal excitation of the fields. The m.m.f. *OD* therefore causes little change in the flux ϕ_M, the value of which remains practically constant, and consequently the voltage generated in the conductors over the arc *AB* is constant and independent of the load on the generator.

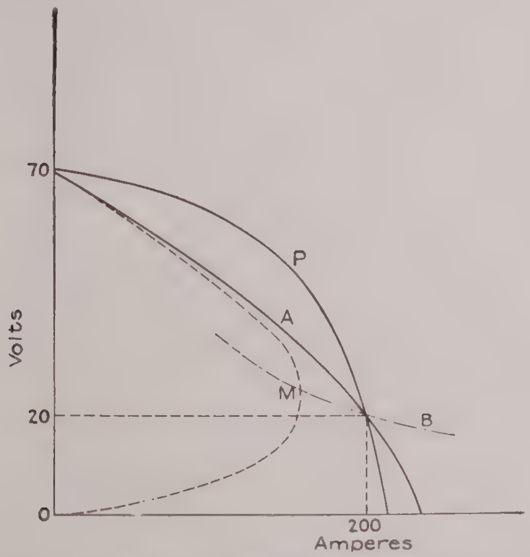

Fig. 1. Voltage-current Characteristics of a Single-operator Arc Welding Generator. (A) is the most desirable characteristic for arc welding. (M) is the characteristic of a self-excited generator showing instability. (P) approaches instability and this generator will be sluggish

Advantage is taken of this fact by placing a third brush at *B* and utilizing the voltage *AB* to supply the constant potential necessary to maintain constant excitation of the fields, thereby eliminating the need for a separate exciter. Continuing with the theory of the fluxes: the poles carrying the cross flux are not saturated so that the m.m.f. *OE* due to the armature current causes a decrease in ϕ_C proportional to the load. Sufficient increase in load will cause a reversal in the direction of the cross flux, building it up in the opposite direction. Therefore, the voltage between *B* and *C* changes in proportion to the generator load. The generator voltage *AC* is equal to the algebraic sum of *AB* and *BC*. The generator is designed to give 70 volts at no load, at which time $AB = BC = 35$ volts, hence $AC = AB + BC = 70$ volts.

On short circuit, $AC = 0$ so that $AB = -BC$ and therefore the current delivered on short circuit will be of such magnitude that the cross flux produced thereby will be equal to the cross flux at no load, but of opposite direction. For any intermediate value of line current there is a definite corresponding voltage. Suppose that 200 amperes generates a voltage of −15 volts in the quadrant *BC*. Since the potential in *AB* is constant and equal to 35 volts the terminal voltage of the generator will be $AC = AB + BC = 35 - 15 = 20$ volts which is the arc voltage. Any increase in the arc voltage decreases the current and a decrease in arc voltage increases the current.

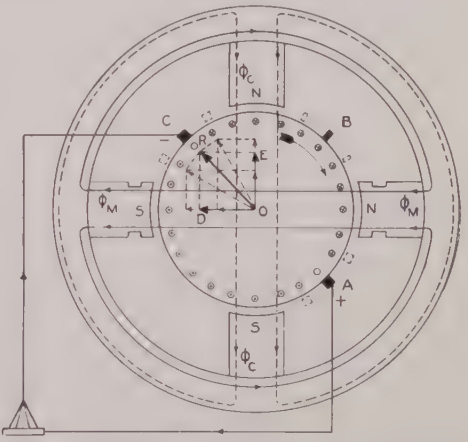

Fig. 2. Elementary Diagram of Generator Showing the Paths of the Magnetic Circuit, the Position of the Brushes, the Armature Reaction, and the Effect of Shifting the Brushes

The voltage-current characteristic of this generator is therefore that of a compound generator with a strong differential series field and a separately excited main field. To obtain the necessary current adjustment the brushes are shifted, thereby changing the direction of the armature reaction *OR*, thus altering the value of the component *OE* and in turn ϕ_C for a given value of armature current. The component *OD* is also changed but since the main field poles are saturated this change in m.m.f. has little effect on ϕ_M. Reference to the dotted vectors in Fig. 2 will explain this action.

Shifting the brushes in the direction of rotation increases the component *OE* for a given value of *OR* and therefore reduces the voltage for a given current, while a shift in the opposite direction decreases the value of *OE* and increases the terminal voltage corresponding to a given current. Therefore, by shifting the brushes an effect similar to changing taps on the series field of a differentially compounded generator is obtained, except that an infinite number of steps may be had by shifting the brushes whereas only a limited number of taps on a series field are possible. The excitation voltage *AB* changes somewhat due to a brush shift but the main field poles are saturated and therefore the no-load voltage is altered but slightly. Fig. 3 shows six of the infinite possible number of characteristic curves obtainable from the latest design of arc-welding generator of this type.⁽¹⁾ These curves are similar to *A* in Fig. 1, though characteristics approaching either *P* or *B* can be obtained. Since the heat generated in an electric arc is equal to the product of the arc voltage and the arc current, and since a constant rate of metal deposition requires the absorption of heat at a constant rate, it might be concluded that a generator with a "constant energy" characteristic similar to *B* in Fig. 3 would be ideal. But it must be remembered that the longer the arc length the more heat is lost to the air by convection and radiation so that a characteristic similar to *A* with more energy at the higher voltages is needed to compensate for this loss. Characteristic *P* however carries this principle too far. Also in any self-regulated machine, whether of the divided magnetic circuit or the differentially compounded type, the change in load current due to a change in arc voltage is utilized to effect the necessary change in flux required by the change in voltage. A characteristic similar to *P* then means that throughout the low-voltage or welding range of the generator, the change in line current for a given voltage change is small and the generator does not so quickly adjust itself to changes in arc length but is sluggish in operation. In other words, curve *P* approaches curve *M*, which is admittedly unstable at low voltages. Therefore, all things considered, characteristics of the type shown in Fig. 3 are the most desirable for arc welding and have consequently been built into this generator.

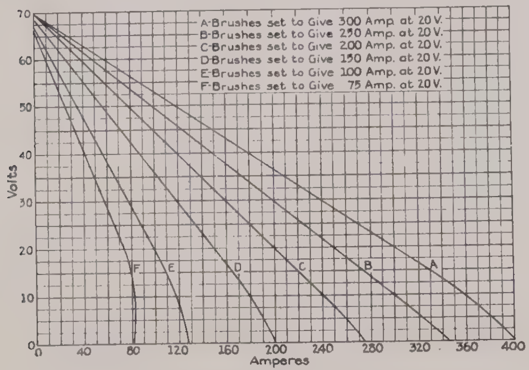

Fig. 3. Voltage-current Characteristics of the Generator for Six Different Brush Settings

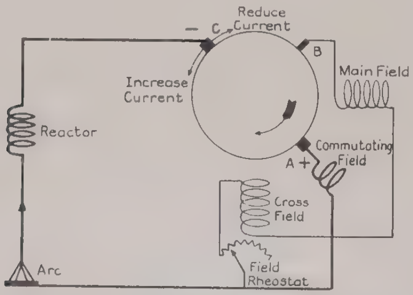

Fig. 4. Simplified Diagram of Generator, showing the arrangement of the field windings and the shifting of the brushes by which the current-voltage characteristic may be changed

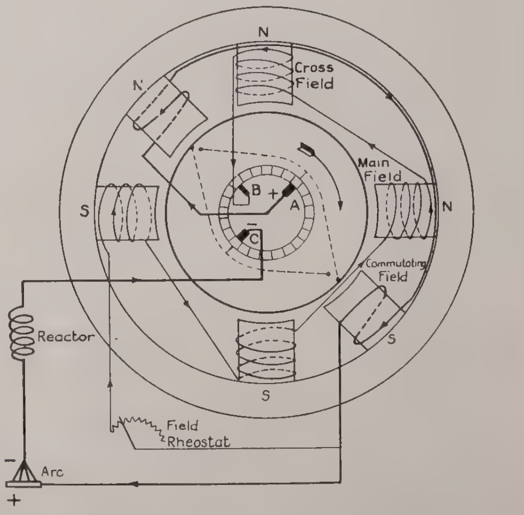

Fig. 5. Development of Fig. 2, showing the electrical and magnetic circuits with the addition of commutating poles and an external reactor

Present day design of direct-current generators demands the use of commutating poles placed at the points *A* and *C* (Fig. 2) from which the load current is taken, and under the influence of the commutating poles the brushes collect the current without sparking. Although this commutating winding opposes the armature reaction and sets up a very weak "commutating" flux, it does not affect the magnetomotive force of the armature and therefore does not change the

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(1) Identified by the trade designation WD12.

cross flux or main flux nor alter the characteristics of the generator. The commutating poles of this generator cover a large arc since the commutating zone must include the coils being commutated throughout the range of the permissible brush shift. No commutating pole is needed at *B* since the current collected by the brush at *B* is very small.

Fig. 4 gives a diagram of the electrical circuits of the arc welding generator showing their extreme simplicity. A more elaborate diagram of the generator showing both the electrical and magnetic circuits is shown in Fig. 5. This also shows the use of a reactor in the welding circuit for steadying the arc. The reactor serves the same purpose as a surge tank on a hydraulic penstock, and is of considerable service to the operator in smoothing out the current fluctuations incident to arc welding. The apparent change in position of the brushes in Fig. 5 from that in Fig. 2 is explained by the fact that due to the arrangement of the end connections of the coils, the commutator bars in drum wound armatures are usually ninety electrical degrees from the coils to which they are connected. Welding experience dictates that the current in the arc for most classes of work must flow from the work toward the electrode, the positive terminal of the machine being grounded. One end of the field is therefore connected to this grounded terminal to prevent insulation strains.

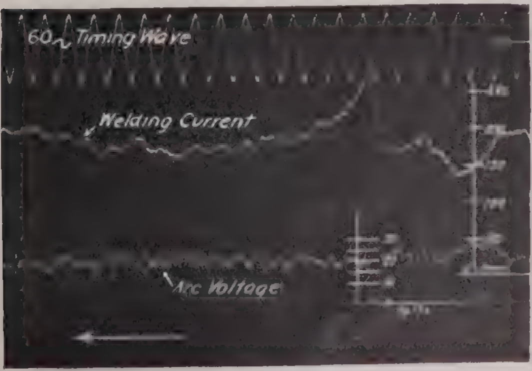


Fig. 6. Oscillogram of a Single-operator Arc Welding Generator, showing the instantaneous interaction between arc voltage and welding current

The application to welding work of this self-contained generator requiring no exciter or variety of field coils for various voltages, enables the manufacturer to produce a single type of machine and stock it as he would any other standard product. It may then be used as a belt-driven machine or connected to a direct-current or an induction motor.

The no-load voltage of from 60 to 70 volts facilitates the striking of the arc while the performance characteristic as shown in Fig. 3 is close to the ideal for arc-welding. Current adjustment is obtained by turning a handwheel, which shifts the brushes slowly and accurately by means of a worm gear. For the guidance of the operator in adjusting the machine, a pointer attached to the brush rigging is arranged to move over a graduated sector, thus indicating the current setting of the generator.

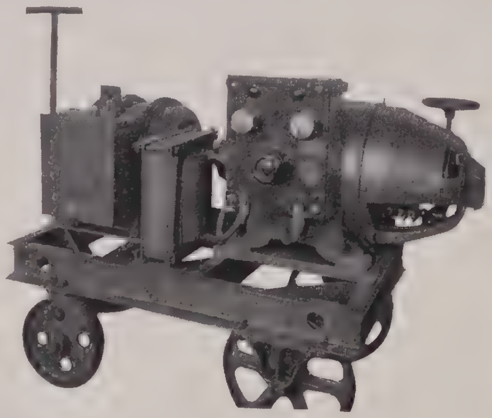


Fig. 7. Front View of the Single-operator Arc Welding Motor-generator Set complete with starting and control equipment and reactor all mounted on a truck for portable use.

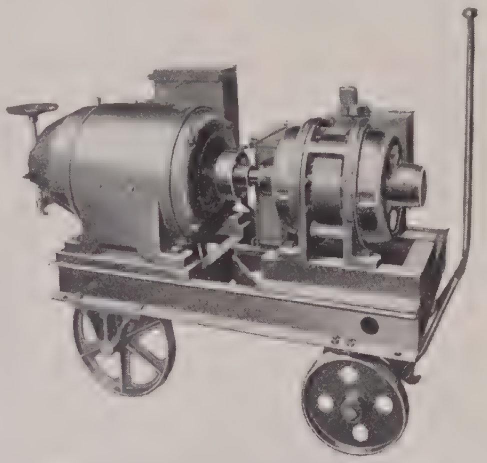


Fig. 8. Rear View of the Welding Equipment Shown in Fig. 7

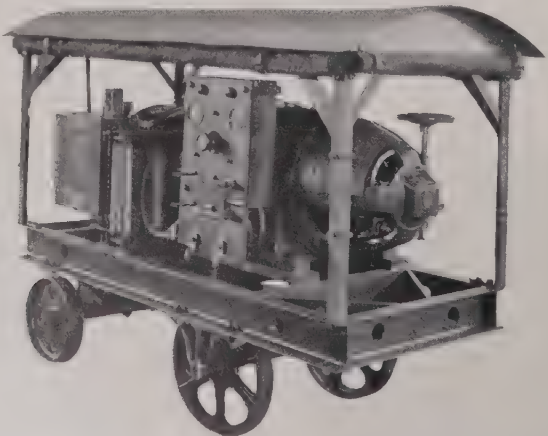
The wiring connections are extremely simple, the generator being devoid of complicated field windings or taps. For a 20-volt arc the current adjustment ranges from 75 amperes to 300 amperes with an infinite number of intermediate steps. The instantaneous action between voltage and current in this generator is shown by Fig. 6 and is due largely to the fact that the armature which generates the voltage is also the seat of the regulating action. Obviously this is the closest relation possible and accounts for the powerful and responsive arc produced by the machine.

This generator is rated 6¼ kw., 25 volts, 250 amp. for one hour with a temperature rise of 50 deg. C. It will give 200 amp. continuously with the same temperature rise, and will furnish 300 amp. for short periods.

This generator is usually combined with a 10-h.p. induction motor. Figs. 7 and 8 show such a set complete with starter for the motor, reactor, and generator panel all mounted on a portable truck forming a complete unit. The meters on the generator panel keep the welder informed of voltage and current. The handwheel for shifting the brushes is mounted conveniently at the end of the generator, and the commutator is protected by a cover. The small rheostat in the generator field is used as an aid to obtaining fine regulation for welding on light work. For ordinary operation it is not required and need never be adjusted.

Electric Welding in Railroad Shops

Following a long and intensive study of the relative merits of gas and electric welding, the Chicago, Burlington and Quincy Railroad has decided in favor of electricity and has taken the first step in supplying its erecting shops and engine houses with this type of equipment. The installation will soon consist of 45 portable electric arc welders of the type shown in the accompanying illustration.



The welding equipments are of the latest design, using the split-field generators described in the preceding article and are mounted complete on four-wheel trucks. For protection against the weather and the rough treatment encountered in railway shops, each outfit is provided with an arched metal roof and curtains which may be rolled down on all four sides. A special time saving feature is a polarity reversing switch mounted on the generator panel, which enables the operator to adapt the machine quickly for work on light-gauge non-ferrous metals.

Percy Electric Dog and Taper Device for Saw Mill Carriages

By J. J. Tallman and C. A. Binns
Union Lumber Company, Fort Bragg, California
San Francisco Office, General Electric Company

Because logs vary one from another and each presents a problem to secure the maximum of high-grade lumber, it has been considered necessary to use manual labor to handle the logs while on the saw mill carriage. This expensive method of handling is no longer required, since the recent development of more flexible and effective dog and taper devices that are electrically operated. The new equipment, described in this article, has proved so easy to manipulate that one man can now handle all the operations on the saw carriage, where formerly as many as five men were sometimes required. At the same time the dangers of manual handling have been eliminated, making the development one of great value from the standpoints of safety, economy, and speed.—Editor.

Among the few saw mill operations which, until a comparatively recent time, were considered impossible to change to individual electric drive were those of the dog and taper devices on the log carriage.

These are most fascinating operations to watch, and any one who has seen a saw mill in operation cannot help remembering the two to five operators of the dogs and setting devices riding back and forth on the carriages in front of the saws—a job which may easily be considered hazardous. In addition, it is inefficient because the labor charge is very high.

With the idea of correcting the deficiencies of this most common method, E. H. Percy, Chief Engineer, J. J. Tallman, Chief Electrician, and E. L. Swinhart, Master Mechanic, all of the Union Lumber Company of Fort Bragg, California, undertook to develop dog and taper mechanisms which would operate entirely electrically. Their efforts met with complete success. The management of the Union Lumber Company gave its full co-operation to the development with the result that now on the north side saw only one operator rides on the carriage and handles all devices from one station, sitting back of the setting device. All hazard has been removed, and quicker and more efficient operation has been obtained.

The first installation of these devices on the carriage of the north side saw, on July 8, 1923, met with remarkable success. They have been in continuous operation ever since and have given entire satisfaction, even exceeding the expectations of the designers.

Description of Manual Method

Saw mill carriages are used for mounting and holding the logs in position while passing them back and forth in front of the saws to cut the logs into lumber. The carriage usually has two or more headblocks for the logs to rest on and for guiding the knees on which are mounted the dogs for holding the log from rolling or moving endwise while being sawed. These knees are also equipped with a taper device or offset, moved by a lever for advancing one knee ahead of the others when one end of the log is small, so as to saw parallel with the face of the log, and then take out a wedge-shaped piece from the center of the log where it may be split or decayed. These devices have commonly been hand-operated, requiring for fast work an attendant at each knee. The knees are movable on the headblocks by a setting mechanism for advancing the log toward the saw as each board is sawed. The taper device is very hard to move at times and dangerous when a log is being turned. Ordinarily, hand dogs are not effective in holding springy, irregular or hard timber, and they also mar the finished side of the log when it is against the knee; hence the need of improved devices which can do this work effectively and reduce to a minimum the number of attendants on a carriage.

Devices using air as a power medium have been developed and are in use, which eliminate some of the disadvantages of the hand method.

Description of Electrical Method

Fig. 1 provides a photographic description. It shows a four-headblock carriage equipped with an electric tongs dog and taper on the farther or No. 1 headblock, with similar equipment on No. 3 and No. 4 headblocks, while No. 2 has what is called a hook dog. The tongs dogs are used for holding small and partly sawed logs, while the hook dog is used for holding large round logs, until one side is sawed flat. The improved motor-operated taper may be set at any fraction of an inch up to six inches, being an improvement over the hand set which was adjustable by one and one-half inch notches only.

The Tongs Dogs

In Figs. 2 and 3 tongs dogs are shown in the open position ready to receive a log, and in Fig. 4 a dog engaging a chunk of wood to demonstrate how firmly the device holds a log from the top and bottom sides. The tongs consist of two long arms, the forward ends of which are fitted with curved points or dogs for engaging the log, and are guided by a tee slot in a casting bolted to the knee, while the rear ends are pivoted on a movable arm and slot. Both arms are free to move up or down and are connected together by a rack which engages a pinion operated through a gear train by the motor which is mounted on the top arm. The motor has a spring-tension brake and wheel opposite the drive pinion, and these hold the top arm at any place it may be stopped. The motor has sufficient torque to overcome the brake and do the necessary work without heating.

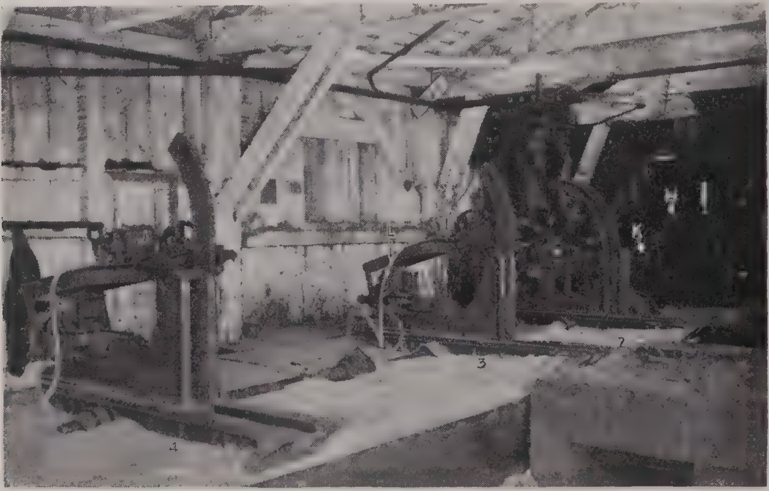


Fig. 1. Electrically-operated Tongs Dogs, Hook Dog and Taper Devices Installed on Four-headblock Saw Mill Carriage

The Taper Device

In Figs. 2 and 4 it will be noted that the pinion of the lower motor is meshed with a gear which by means of a screw moves a crosshead shown in Fig. 3. The lower end of this crosshead is connected by a link to a rack inside the knee. It is evident that when the rack is stationary the crosshead is also stationary, and that by operating the motor the screw will revolve and the knee be moved forward or backward at the operator's will. Stops are provided so that the knee may be lined up in an instant in the back position. The gear meshing with the motor pinion is provided with a helix hub to prevent the screw jamming the crosshead when lining up against the stops. There also is an indicator on each block (*O*, Fig. 2) by which the operator can tell at a glance the exact position of the device at any instant.

The Hook Dog

Fig. 5 shows the hook dog, which consists of a crank arm, the upper end of which is curved and fitted with a spike for engaging the log. The lower end is fastened to a large gear by a hinged joint which has a limited movement owing to the lugs on the lower end of the arm engaging a gear face. This gear together with other reduction gears and the motor are mounted on a cast-steel frame pivoted from the base and cushioned with springs. The motor has a solenoid brake which proves to be better than the spring-tension brake for providing the greater holding power necessary to prevent the log rolling after it has been "dogged."

Electrical Equipment

The tongs and taper devices are operated by 2.2-h.p., 1200-r.p.m., 440-volt, totally

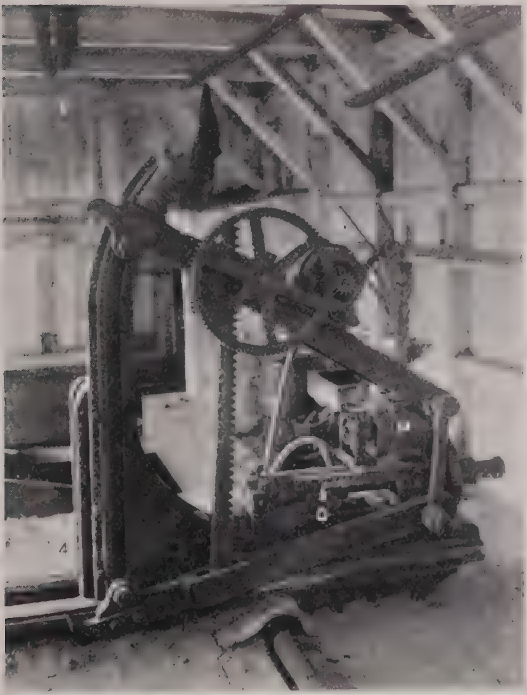


Fig. 2. Electric Tongs Dogs in Position to Receive a Log

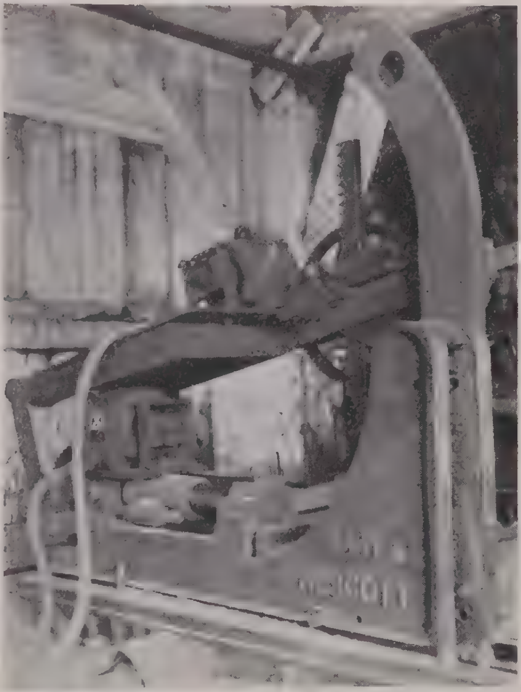


Fig. 3. Another View of Tongs Dogs and Taper Device

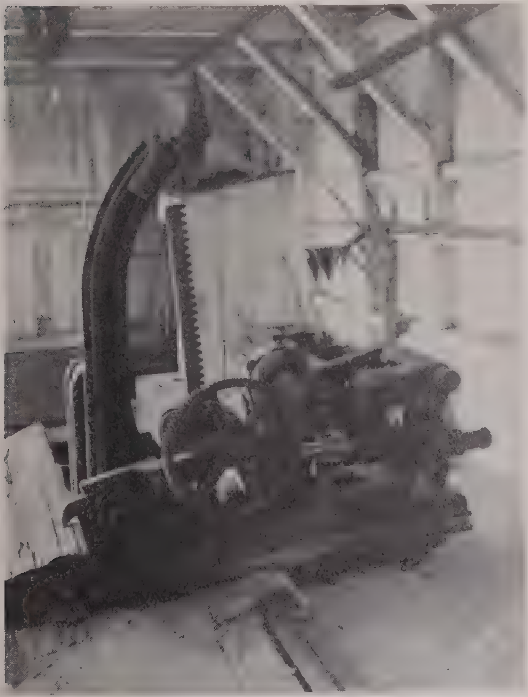


Fig. 4. Tongs Dogs Engaging a Block of Wood for Sawing, Showing Rack and Pinion Method of Applying Electric Drive

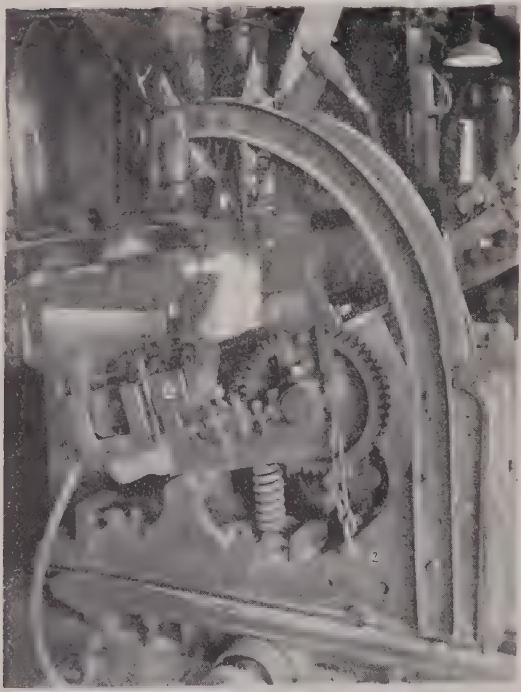


Fig. 5. Motor-driven Hook Dog Mechanism, Used for Holding Logs While One Side is Being Sawed Flat

enclosed, high-resistance-rotor-type induction motors⁽¹⁾ with double-end shafts for brake wheels (*H*, *I*, *J*, *K*, *L*, *M*, Figs. 1 to 6). The hook dog motor is of the same type but of 2.8 h.p. and equipped with an electric solenoid brake (*F*, *G*, Figs. 5 and 6).

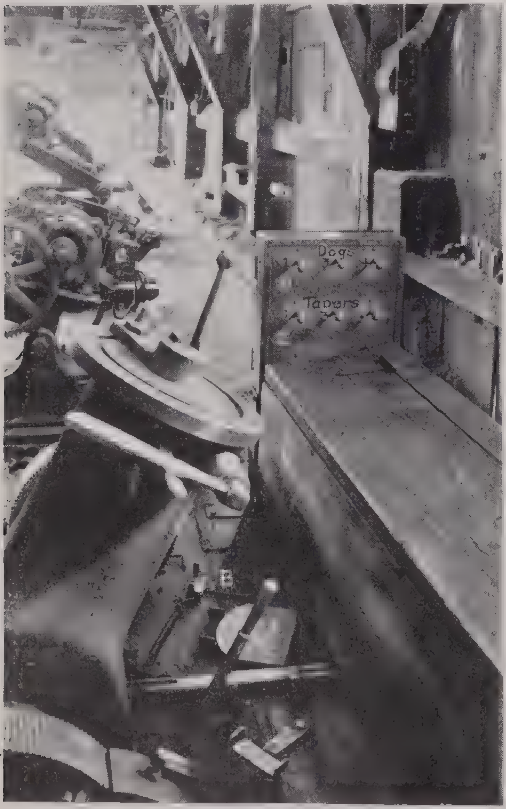


Fig. 6. Log Carriage Control. Seated on this bench one man can perform sawing operations which often required five men by the manual method

The control is central and selective, and is operated by three master drum reversing switches⁽²⁾ mounted under the floor of the carriage, one each for the tongs dogs, *C*, hook dog, *A*, and taper devices, *B*, respectively (Fig. 6). The electric current is taken from a trolley collector (*N*, Fig. 5), mounted on the carriage in the usual way, to the master drum switches which are operated by foot pedals from the operator's seat (*A*, *B*, *C*, Fig. 6). It is then run in flexible armored conduit to a fuse cabinet and selective switches at the end of the operator's seat (*D*, *E*, Fig. 6). There are two sets of bus fuses in this cabinet, one for the tongs dogs and one for the taper device motors. The current then goes to the selective switches operated by push rods through the front of the cabinet, the three top ones, *D*, controlling the tongs dogs and the bottom three, *E*, the taper devices. By leaving any one or a combination of switches *in*, the corresponding motors will run when the master drum switch is operated. A schematic wiring diagram is shown in Fig. 7.

Operation

A log is rolled onto the carriage headblocks and placed against the knees by a log turner or "steam nigger," the hook dog is immediately operated, the spike engaging the log and the crank arm clinching it to the knee. After one side of the log is sawed flat the hook dog is released and the log turned face down on the headblocks. The tongs dogs are then operated, using as many as necessary to hold it, the top arms moving down until the points engage the log, then the lower arms lifted by the racks until they also engage the log, the entire operation requiring only a few seconds and handled all by one operator instead of one at each knee.

The taper device is used only when sawing tapered telegraph poles or sawing parallel with the face of the log, after which the knees may be lined up and a wedge shaped piece taken out at the center where it may be rotten or split. A good carriage operator always judges his log in advance and has the carriage adjusted to receive it, thus saving time.

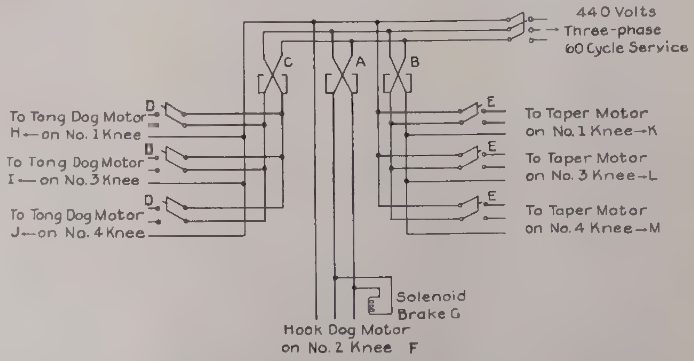

440 Volts
Three-phase
60 Cycle Service
C
A
B
D
To Tong Dog Motor H ← on No. 1 Knee
D
To Tong Dog Motor I ← on No. 3 Knee
D
To Tong Dog Motor J ← on No. 4 Knee
E
To Taper Motor on No. 1 Knee → K
E
To Taper Motor on No. 3 Knee → L
E
To Taper Motor on No. 4 Knee → M
Solenoid Brake G
Hook Dog Motor on No. 2 Knee F

Fig. 7. Schematic Circuit Diagram of the Electric Installation for Handling Logs on the Saw Carriage

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(1) Identified by the trade desgnation "Type KTE."

(2) Of the type identified by the trade designation "RD-80."

The following points of superiority have been demonstrated:

(1) Greater saving in lumber due to better holding.
(2) Log prevented from rolling.
(3) Log prevented from shifting endwise.
(4) Log prevented from springing from knee.
(5) Firmer grip eliminates snaky lumber.
(6) Back board is not marred, as it is gripped on the edge.
(7) Fewer attendants required on a carriage, lowering operating costs.
(8) Small amount of power required, as it is used only for short intervals.
(9) Heavy, substantial points do not need repairs; previous types did.
(10) No danger to operator moving taper device while log is being turned.
(11) Very simple control which an operator learns to use effectively in a few hours.
(12) A clear carriage floor, as all wiring is carried under the floor in flexible armored conduit.

Control Equipment for Motor and Trail Cars on the Java State Rys., Dutch East Indies

By Frank Guillot

Railway Equipment Engineering Dept., General Electric Company

A healthy growth in population and business is not possible without efficient and economical transportation. The continued dependence upon a transportation system that has become inadequate results in unnecessary congestion and handicapped activity. One of the latest substitutions of the new for the old is about to take place on the Island of Java where a section of the State Railways is undergoing electrification. The rolling stock will consist of 1500-volt motor and trail cars with control equipment so arranged that trains can be made up of several of these units. The following article furnishes a complete description of the control equipment, and its operation, which includes the hitherto unusual feature of electric dynamic braking in train operation.—Editor.

One of the most interesting electrification developments in the Far East is that around the city of Batavia in the Island of Java. The necessity for this development has been produced largely by the physical and geographical conditions surrounding the growth of that city.

The city of Batavia was founded in 1619, at the mouth of the Cjiliwoeng River. This formed a convenient harbor for ships of the size in use at that day. The city grew up along the banks of the river until now it has become long and narrow, and occupies practically only two streets which run parallel to the river. The residence portion at Weltevreden is now seven miles from the business section. Transportation between these two is furnished by a steam tram hauling three or four trail cars and running through the single street of the city. On account of traffic congestion and the slow acceleration and braking, the schedule is slow.

During the growth of the city the old harbor became shallow on account of the gradual deposition of silt, and with the development of modern vessels of deeper draught it has become necessary to develop a new harbor at Tanjong Priok, about seven miles east of the old harbor and city of Batavia.

On account of this wide distribution and the necessity for conveying all material from the harbor either to the city of Batavia or to Weltevreden as well as on account of the necessity of rapid passenger transportation between these points, it has been decided to electrify the network of steam roads connecting the various points in this district. The first section of this electrification will be a length of 15.6 km. (9.68 miles) extending from Tanjong Priok to Mr. Cornelis, the freight center near Weltevreden. After this the next section will be that extending from Batavia to Weltevreden, and succeeding this the sections extending to suburban towns.

The Java State Railways have recently purchased ten motor and trail car equipments for the electrification of the section extending from Tanjong Priok to Mr. Cornelis. The cars are designed to operate singly, or in train units consisting of one motor car and one trail car, and the train assemblage consists of from one to four of these units.

The ultimate source of power for this electrification will be from a hydro-electric power house at Tjitjatih or Oebroeg, 89 km. (55.31 miles) from Mr. Cornelis. From this station three-phase, 70,000-volt transmission lines will conduct the power to a substation at Mr. Cornelis and one at Antjol, 4.4 km. (2.73 miles) from Tanjong Priok where it will be converted to 1500 volts direct current at which the trains will operate.

The cars, weighing approximately 42 tons, are equipped with all modern appliances for comfort and safety of passengers as well as for ease and economy of operation.

The motive power of each motor car consists of four 115-h.p. 750/1500-volt motors with electro-pneumatic cam-operated multiple-unit control.

The control equipments do not differ materially in design and construction from similar apparatus previously described in the General Electric Review.(1) The following, therefore, is intended to cover only some of the later features of interest.

The motor controller used in these equipments provides for connecting the two motors permanently in series for normal operation from the 1500-volt trolley; two groups being connected in series and in parallel. In conjunction with an electro-pneumatic change-over switch, rheostatic braking is obtained by using the seven series positions of the motor controller.

The energy for operating the magnet valves of the motor controller,(2) rheostatic braking switch, field control switch, pantograph trolley, and other auxiliary apparatus, is taken from a motor-generator set at 65 volts; the motor of this set being operated directly from the 1500-volt trolley.

The acceleration is accomplished through seven series, five parallel, and one field control position of the motor controller.

The resistors are so arranged and proportioned that the current in the motors is evenly divided at all times, thus keeping the tractive effort of the motors balanced.

The transition from series to parallel is accomplished by shunting a pair of the motors through resistance as shown in Fig. 1. The first step is to shunt a resistance across a pair of the motors, at the same time leaving full potential across all the motors connected in series. Momentarily part of the motors are disconnected and reconnected in parallel; this lowers the torque to about one-half for a very small fraction of a second. The maintained torque is sufficient to keep the drawbar springs in tension. This fact, together with the rapidity of the change and the inertia of the train or car, results in a transition in which there is no appreciable shock or surge.

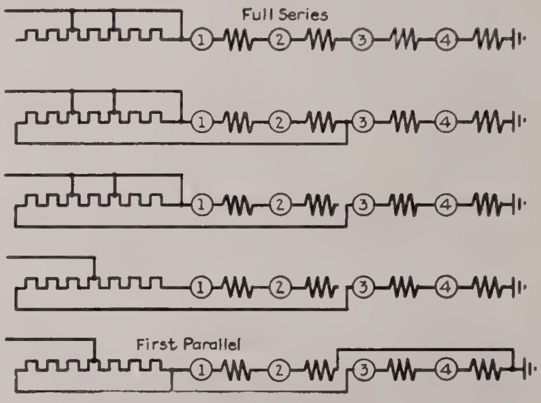

Fig. 1. Steps of Motor Connections During Transition from Series to Parallel

As this method permits connecting all accelerating resistance on the same side of the motors, the resistance can be paralleled so that balanced circuits are maintained after the transfer.

The use of the pneumatically-operated cam shaft for actuating the individual contactors eliminates the need for electrically interlocking these contactors and greatly simplifies the control circuits. Thus it has been possible to obtain automatic acceleration as well as automatic deceleration of all the motor cars in the train without the complication which would have arisen in previous types of train control wherein the closing of the contactor for the first step completed the interlocking circuit for the second step and so on.

Within the motor controller are contained the:

Reverser.

Air engine and cam shaft for operating the contactors.

Eleven contactors (which make the electrical combination of the motors and regulate the starting resistance in circuit with them).

Overload relay.

Accelerating relay.

Braking relay.

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(1) See "Sprague-General Electric PC Control," by C. J. Axtell, Oct., 1915, p. 985; "Recent Developments in the Sprague-General Electric PC Control" by F. E. Case, Nov., 1916, p. 1015; and "Control for 1200- and 1500-volt Car Equipments" by R. S. Beers and C. J. Axtell, Apr. 1920, p. 314.

(2) Identified by the trade designation "PC."

The entire operation of the main motor control, including the electric braking feature, is accomplished by the use of ten magnet valves functioning as follows:

2 for the air engine driving the cam shaft which actuates the eleven main contactors.
2 for the reverser.
2 for the line breakers.
2 for the field control switch.
2 for the electric braking switch.

The 1500-volt motor controller is shown in Fig. 2.

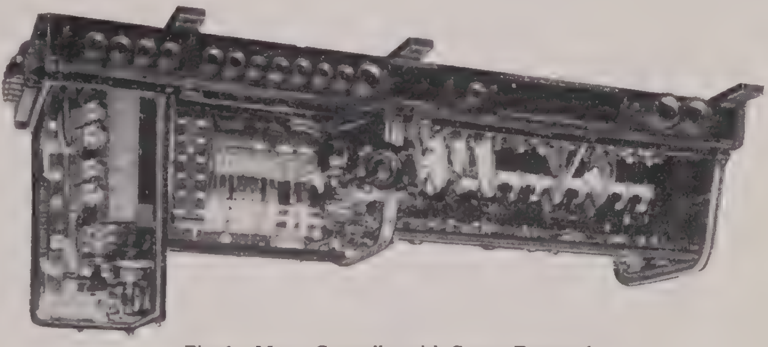

Fig. 2. Motor Controller with Covers Removed

The line breaker consists of two independently operated contactors with extra powerful magnetic blowouts. Each line breaker is closed independently against a heavy spring by means of an air cylinder controlled by a magnet valve. When the control circuit of the line breaker is opened through the master controller or the operation of the overload relay, the motor current is broken by the line breaker before the cam shaft of the motor controller has started to turn off, thus confining practically all arcing to the line breaker. It is so interlocked with the reverser that the reverser cannot be thrown unless both line breakers are open; this insures against operating the reverser with current on the motors. The line breaker is further interlocked with the "off" position of the motor controller through the control drum, so that when the line breaker is opened through overload or by other cause, the motor controller must return to the "off" position before the line breaker can be closed again (see Figs. 3 and 4).

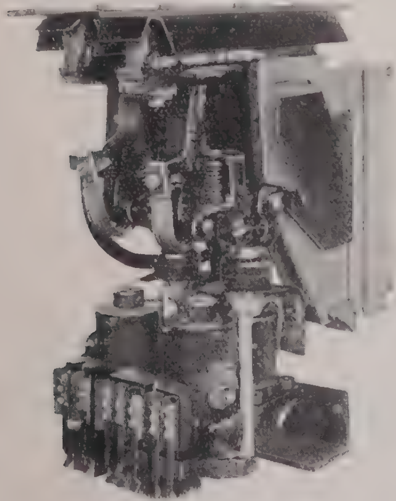

Fig. 3. Line Breaker with Cover Removed to Show Magnet Valves and Interlock Mechanism

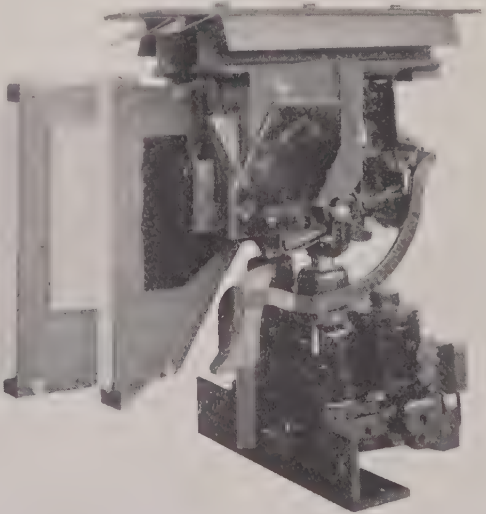

Fig. 4. Front View of Line Breaker with One Arc Chute Removed, Showing Arcing Horns

The master controller is consistent in size and weight with the low voltage and light control current it handles. The notches or positions of the main drum are five in number and are as follows:

(1) Switching
(2) Series
(3) Bypass series
(4) Bypass parallel
(5) Parallel

The reverse drum, in addition to the usual "off," "forward," and "reverse" positions, has a forward brake and reverse brake position.

The dead-man's release feature contained in this controller operates by opening the control circuits, and applying the emergency brake by means of a pilot valve, when the main handle is released.

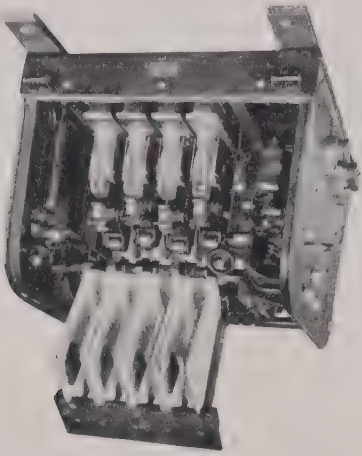

Fig. 5. Field Reducing Switch with Cover Removed

An electro-pneumatic field control switch is used for reducing the strength of the motor fields to obtain maximum speeds. This switch consists of four cam-operated contactors, like those used in the motor controller, operated by means of a similar cam shaft and small air engine. It has two magnet valves which, when energized, cause the switch to throw to the weakened field position. These valves can be energized only when the motor controller is in the last parallel position and not until the motor current flowing through the series coil of a current-limit relay, included in the field control switch, has fallen to a predetermined value. Fig. 5 shows this switch with cover removed.

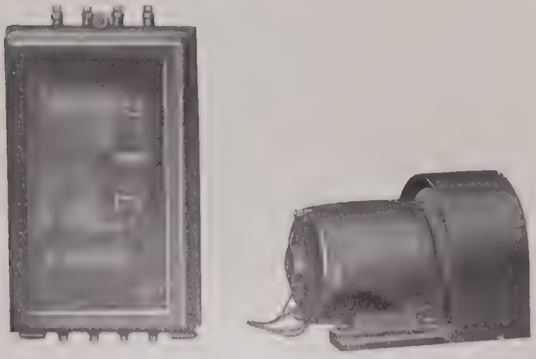

Fig. 6. Voltage Regulator and Counter E.M.F. Motor

Energy for the control, lights, headlights, and other auxiliaries is supplied from a 4-kw., 65-volt generator directly connected to a 750/1500-volt motor. This machine is totally enclosed. The magnet frame is cylindrical in form and is provided with feet by means of which the set is suspended from the under side of the car body. The generator voltage is held constant by means of an external regulator (Fig. 6) operating on the generator field.

The voltage regulator consists of a main control magnet in series with resistance connected across the generator terminals. The operation of this magnet cuts in or out the field of a counter e.m.f. motor, the armature of which is in series with the generator field. This small counter e.m.f. motor gives a voltage which is opposed to the field of the generator under control and works in conjunction with the main control magnet in holding the generator voltage constant. An over-voltage relay is used to prevent sudden rises of the generator voltage if a large portion of the load is thrown off at any time. This relay with its resistance is connected across the generator line. Its function is to insert a resistance in series with the generator field, or short circuit this resistance as occasion requires. The relay is usually adjusted so that its contacts open if the generator voltage rises to approximately 8 per cent above normal. The scheme of connections of the voltage regulator is shown in Fig. 7. Fig. 8 shows the motor-generator set.

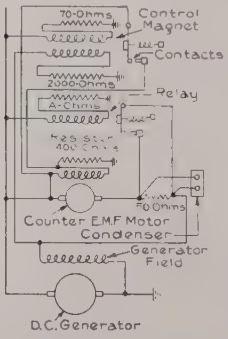

Fig. 7. Diagram of Connections for Voltage Regulator Shown in Fig. 6

As the motor-generator sets for these equipments are required to have sufficient capacity to supply energy for the control, lights and auxiliaries of the motor car, as well as for the lights and auxiliaries of the trail car, it is obvious that during the daylight hours when no lighting load is carried each generator will have sufficient capacity to handle the control and auxiliaries of two or more train units, each consisting of one motor car and one trail car. It is then desirable to be able to stop the motor-generator of any one or more motor cars in the train and select energy from a motor car ahead or in the rear. This control is obtained through an electro-pneumatic switch controlled by energizing or de-energizing its magnet-valve coil through a push-button unit in the control switch located in the motorman's cab. The main contacts of this switch are fitted with blowouts suitable for opening the 1500-volt motor circuit and interlocks which complete the generator circuit to the car panel when the main contacts are closed, or open the generator circuit when the main contacts are open, and establish a two-conductor bus line through the car. The main contacts are held closed by spring pressure when the magnet-valve coil is de-energized, and are closed by air pressure against the spring when the magnet-valve coil is energized. Fig. 10 shows the appearance of the motor-generator control switch, Fig. 12 the simplified connections.

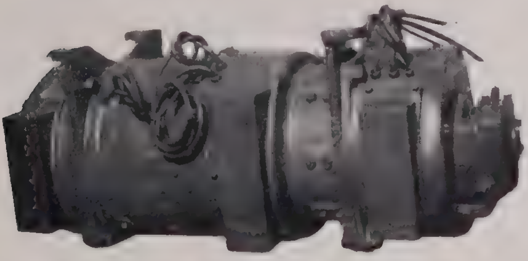
Fig. 8. 1500/65-volt Motor-generator Set

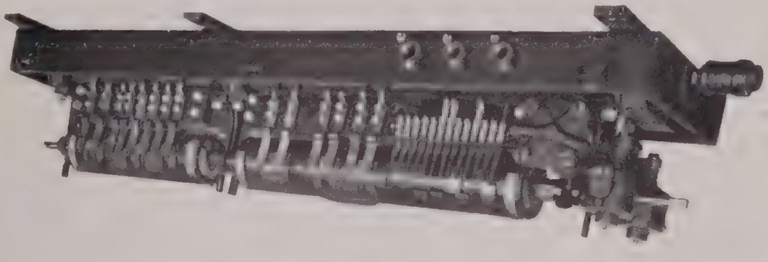
Fig. 9. Motor Cutout and Change-over Switch

A standby battery is used to supply energy to the control and emergency lights for limited periods in the event of failure of power. The battery is kept charged by being floated across the generator and is automatically cut in or out of the generator circuit, as occasion demands, by means of two relays. A battery-potential relay serves to connect the battery across the generator, and a differential relay to disconnect the battery from the generator in case of a serious drop in the generator voltage, thereby protecting the battery against discharging to ground through the generator armature.

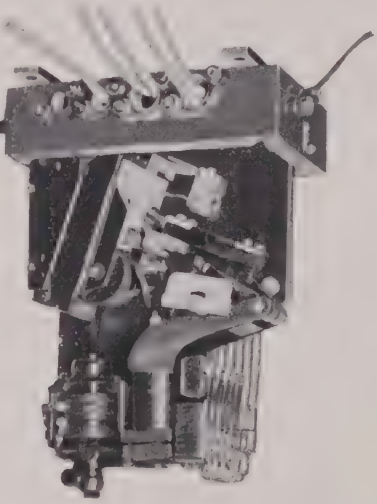
Fig. 10. Electro-pneumatic Motor-generator Control Switch

Figs. 11 and 12 show the elementary circuits of the power and control equipment.

The curves shown in Figs. 13 and 14 are of the current required for the acceleration

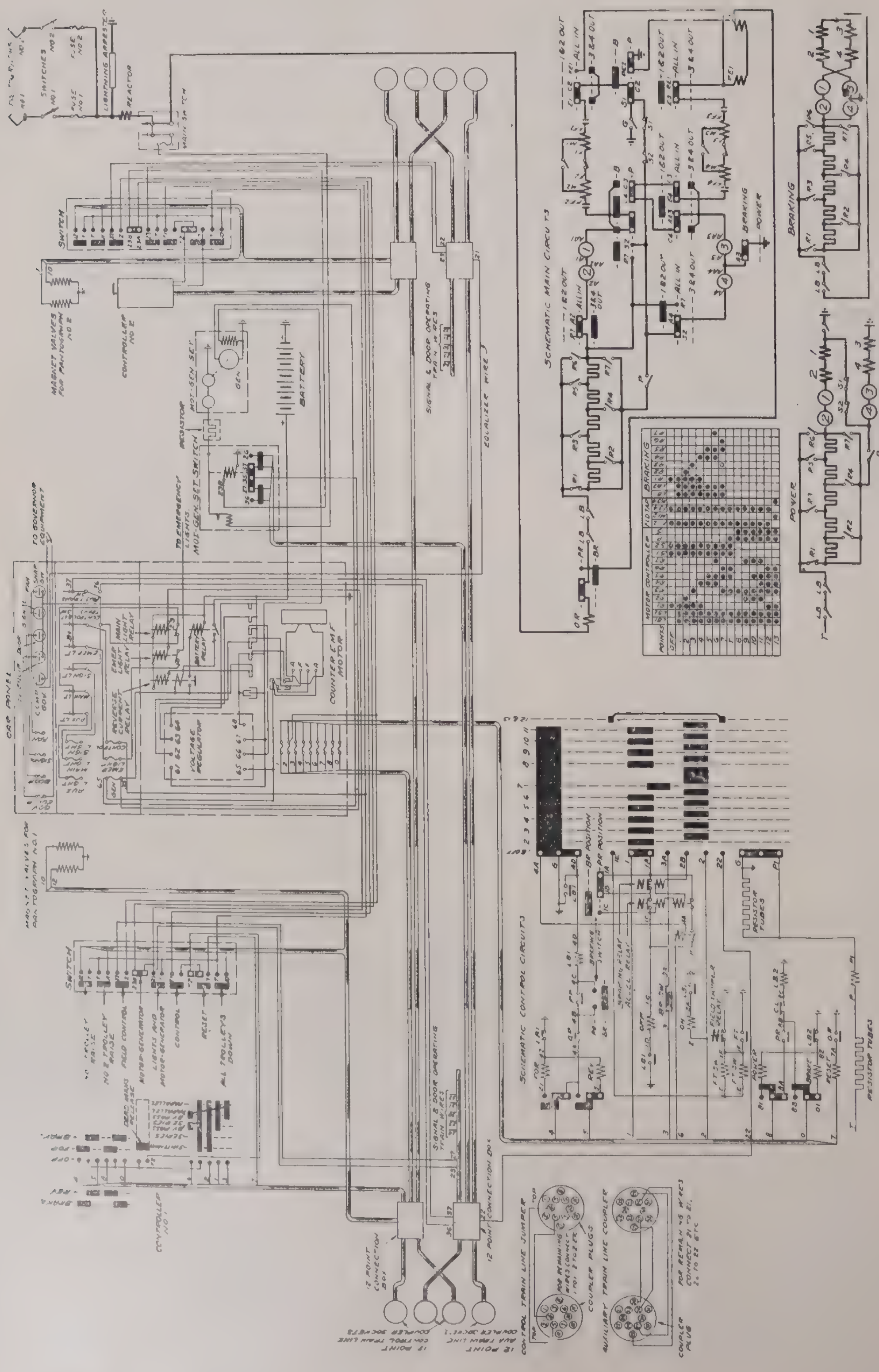

Fig. 11. Diagram Showing Elementary Connections of Control and Power Circuits

of a motor car while that in Fig. 15 is for the acceleration of a motor car and trailer. It will be observed that the first three steps of the curve, Fig. 15, are somewhat lower when compared with the remaining steps, while the acceleration of the motor car alone is obtained with all points fairly uniform. This is due to the fact that the greater train weight being propelled by the same motors requires a much higher tractive effort per motor, and therefore a higher current and less external resistance. In order to obtain the same rate of acceleration for the heavier train as that obtained by the single motor car, the setting of the accelerating relay must be considerably higher. For this reason the curve in Fig. 15 shows that the first three resistance steps are cut out by the motor controller before the accelerating relay begins to operate.

The electric braking feature of these equipments is obtained by changing the connections of the motors to series generators in series with the main motor resistors, the

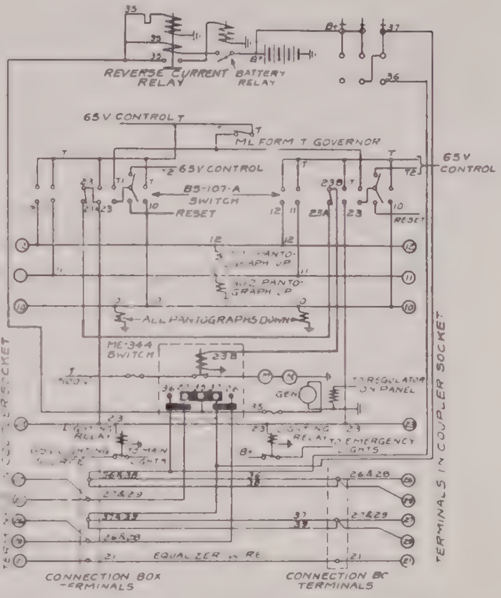

Fig. 12. Diagram Showing Elementary Connections of Auxiliary Circuits

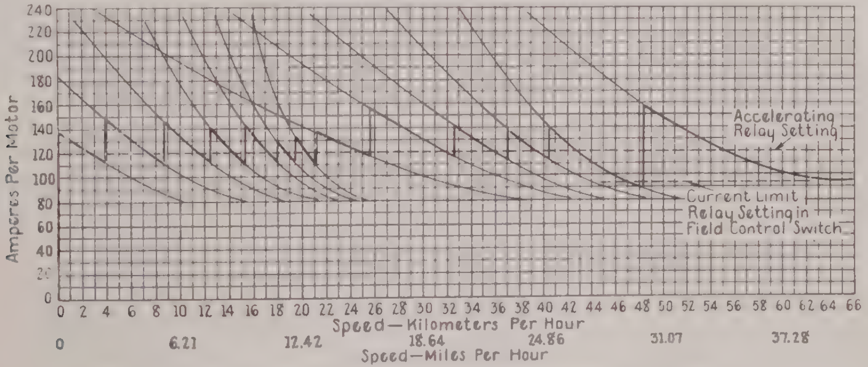

Fig. 13. Calculated Speed-current Curve, Showing Acceleration of Motor Car without Trail Car

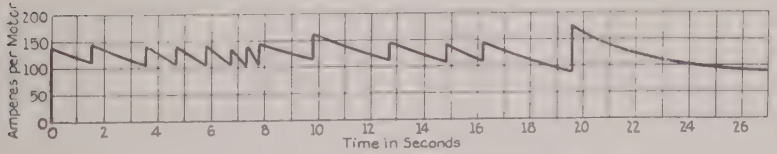

Fig. 14. Calculated Time-current Curve, Showing Acceleration of Motor Car without Trail Car

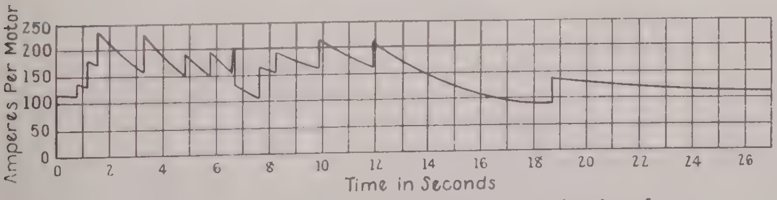

Fig. 15. Actual Time-current Curve, Showing Acceleration of Motor Car with Trail Car

momentum of the car driving the generators. (Two of the motor armatures are grounded during braking which, in effect, protects the insulation by preventing excessive rises in voltage.) The current generated in this manner is dissipated in the resistors. The connections are shown in the lower right-hand corner of Fig. 11. In order to disconnect the motors from the line and obtain the proper combination of connections for electric braking, an electro-pneumatic braking switch is used, Fig. 9. This switch is electrically interlocked with the line breaker, similar to the method of interlocking used for the reverser, so that the switch cannot be thrown from the power to the brake position or vice versa, unless the line breaker is open and power is off the motors. It is further interlocked mechanically through the master controller, so that the reverse drum cannot be thrown to either braking position unless the main drum is in the "off" position.

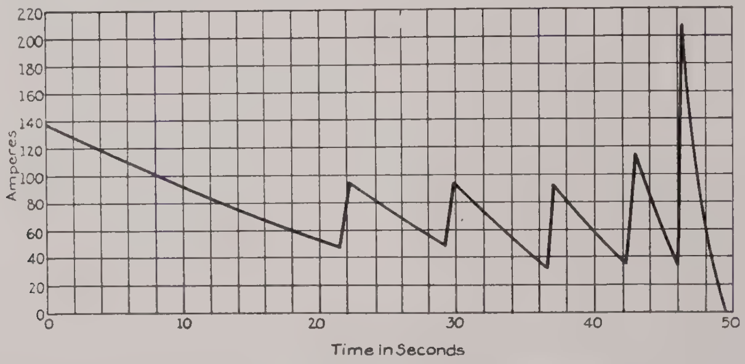

Fig. 16. Curve Showing Current Generated During Rheostatic Braking

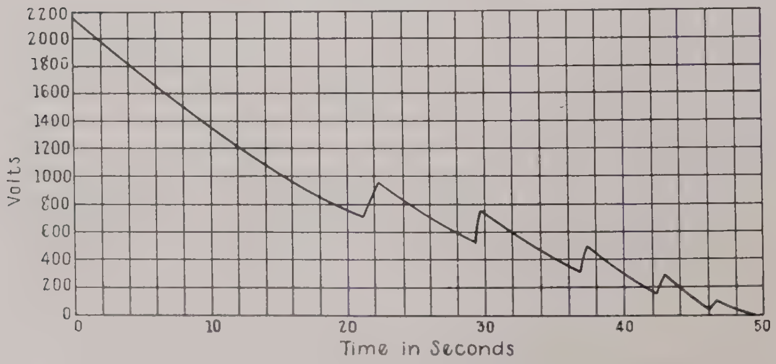

Fig. 17. Curve Showing Voltage Generated During Rheostatic Braking

The rate of braking is governed by means of a current-limit or decelerating relay which acts on the current generated in the converted motors. As the current rises to a predetermined value the relay opens, preventing further progress of the motor controller until the current has fallen to the closing value of the relay, at which time the controller is allowed to advance one step, cutting out another section of resistance. This sequence of operation continues until the full series position is reached.

At any time during deceleration the progress of the motor controller can be arrested, after advancing one point, or its rate of advance increased by means of a bypass feature which has been provided for that purpose. Taking advantage of this feature requires only the manipulation of the main handle of the master controller.

The number of braking points obtained, the time required, and the power consumed in braking are indicated in Figs. 16 and 17.

Rheostatic braking has been used in European countries with satisfaction. The preference for some form of dynamic braking on these equipments is largely due to the influence of European engineering thought. It will be of interest to note the comparative operation between the electric-braking and air-brake systems provided on these cars.

Luminescence or Cold Light

By W. S. Andrews

General Engineering Laboratory, General Electric Company

The subject of cold light has a fascination for everyone, and very frequently we hear the questions asked: "What is it?" "How is it produced?" "Has it possibilities of development for practical use?" Mr. Andrews, who for many years has devoted a large part of his time to a study of light, particularly cold light, answers these questions in a very interesting manner and without resort to explanations difficult of understanding. His tabulations of the various characteristics of luminescence, by class, substance, and nature of exciting radiations, furnish a handy reference summary of these truly beautiful phenomena.—Editor.

The word "Luminescence" was used by Wiedemann in 1888, as a general expression for all light that is not produced by incandescence. Hence it is sometimes termed "Cold Light."

Luminescence appears in nature in a variety of living organisms, and it can also be produced artificially in numerous organic and inorganic substances by proper methods of excitation. It has therefore been classified under sundry headings as follows:

Classes	Produced by
Photo-luminescence	Ethereal waves
Cathodo-luminescence	Cathode rays
Electro-luminescence	Electric stimulation
Thermo-luminescence	Application of heat
Pyro-luminescence	Stimulation of vapors by flame
Chemi-luminescence	Chemical action
Tribo-luminescence	Friction or abrasion

There are also some minor types, such as Piezo-luminescence, produced in some substances by pressure; Crystallo-luminescence, caused by the rapid development of crystals in certain solutions; Lyo-luminescence, which takes the form of weak flashes of light when certain crystals that have been colored by cathode rays are dropped into water. Mention may also be made of Anodo-luminescence, which is produced in many compounds and gases by anode rays, and which is also sometimes termed "Canal Rays." The most important and interesting types however are the seven listed in the above tabulation.

FLUORESCENCE AND PHOSPHORESCENCE

The terms "fluorescence" and "phosphorescence" have come into common use in connection with light that is generated under any class of luminescence. Fluorescence implies the property of emitting light under excitation, which disappears instantaneously on the cessation of the exciting cause; while phosphorescence refers to an afterglow or continuation of light emission after the exciting cause has been cut off.

For example, compounds of uranium are termed fluorescent because the beautiful green light which they emit under the influence of ultra-violet radiation, etc., ceases instantaneously when the latter is shut off. On the other hand, a form of calcium sulphide, known as Balmain's luminous paint, may hold its glow for hours after it has been stimulated, so that it is said to be phosphorescent. *The two terms, however, relate to one and the same phenomenon;* or, in other words, when a substance has become fluorescent it must necessarily pass through a period of phosphorescence during the fading away of its light to total darkness, and in all cases the time of its sustained afterglow, or phosphorescence, is only a matter of degree.

The time necessary for excitation depends upon the substance being subjected to radiation and upon the nature of the exciting source. However, for any one substance there is a maximum useful time of excitation beyond which there is no gain in the brightness of the phosphorescence or fluorescence or in the persistence of the phosphorescence.

The atoms of the various elements are believed to consist of positively charged nuclei, composed of closely packed protons and electrons, each nucleus being the central sun, so to speak, of a planetary system of negatively charged electrons that revolve around it in well defined orbits, in much the same way that the earth and other planets revolve around the sun. It is the composition of the nucleus, and the number and orbits of its family of electrons, that determine the physical, chemical, and electrical characteristics of each of the so-called elementary bodies. When the electrons revolve in their normal orbits they produce no light, but if, by reason of some disturbing influence, they are *put out of step*, we may say, waves in the ether are then propagated which are manifested to us as light. The natural tendency of the planetary electrons is to resume normal conditions as quickly as possible; but so long as the disturbing influence is operating, they must continue in a state of perturbation, and we see what is termed *fluorescence.* When the disturbing influence ceases, the electrons hasten to return to their normal activities, and during this period of settlement, which may be comparatively brief or long, we see the rapid or gradual decay of light which is known as *phosphorescence*.

The period of phosphorescence may also be largely determined by the source of excitation that is used. If calcium tungstate is energized by ultra-violet light from a disruptive spark between iron terminals, it will show a pale blue fluorescence, but no phosphorescence that is detectable by the unaided eye, but if it is excited by x-rays it exhibits a marked degree of phosphorescence.

The foregoing brief remarks are necessarily of a very general character, but the writer believes that they present basic principles in accordance with existing knowledge.

Photo-luminescence

Luminescence can be excited in some substances by visible light, especially in the blue and violet regions, but the effects are usually weak. Sunshine produces strong results in some cases, but the fluorescence is overpowered and masked by the intense visible rays, unless these are absorbed by a suitable screen. Balmain's luminous paint (calcium sulphide) and certain kinds of zinc sulphide are made brightly phosphorescent by sunshine, but to see the best results the exposure should be made by an attendant who should hand the exposed material to the observer in a dark room.

The disruptive electric spark between iron terminals produces a maximum of invisible ultra-violet radiation with a minimum of visible light, so that the fluorescent colors produced are plainly visible without the aid of any screen, as is required with sunlight.

A wide variety of organic and inorganic substances respond to the excitation of these rays, of which the following may be mentioned as representative examples:

Substances	Fluorescence
Various preparations of cadmium..........	Red, orange, and yellow
Willemite (zinc silicate) natural and synthetic	Green
Salts of salicylic acid..	Blue

Many liquids, such as solutions of certain aniline dyes, esculin, quinine sulphate, etc., show more or less fluorescence under these rays but they have no appreciable afterglow.

Under the heading Photo-luminescence, we must also include excitation by x-rays. Barium platino-cyanide shows a pleasing yellow green fluorescence which disappears instantly on the cessation of exposure to the rays. For this reason it is better adapted for fluoroscopic work than calcium tungstate, which, as already stated, shows some degree of afterglow. The latter however is commonly used for intensifying screens, as its luminescence is far more actinic than that of barium platino-cyanide, and its short period of afterglow is not detrimental in this case.

Cathodo-luminescence

When a well exhausted vacuum tube is connected to a source of high voltage, streams of electrons are projected from the cathode terminal in straight lines and excite fluorescence (and sometimes phosphorescence) in compounds that are sensitive to their excitation.

"Cathode rays" is a term generally used to describe these streams of electrons, although, strictly speaking, it is a misnomer, as the words "rays" and "radiation" apply properly to phenomena of the ether. Following common usage, however, the term will be used in this article.

Many compounds which respond only weakly, or not at all, to ultra-violet rays, show a bright luminescence under cathode rays, and most of the substances that are sensitive to ultra-violet rays are also responsive to cathode rays.

There are exceptions however, principally in salts that owe their fluorescent properties to their water of crystallization, which may be abstracted from them in a vacuum. Such, for example, is the case with barium platino-cyanide, which changes from its normal beautiful light green color to a brownish yellow in only a moderate vacuum and then becomes inactive.

Among the substances which do not respond to ultra-violet rays, but which are strongly fluorescent under cathode rays, some of the calcium compounds may be mentioned. Calcined coral is one of them, some specimens of which glow with iridescent colors of indescribable beauty under cathode rays, probably due to minute amounts of foreign matter absorbed from the sea water. Calcined egg shells are also responsive, and rubies exhibit a magnificent red glow, but none of these respond to ultra-violet radiation. Certain compounds of zinc respond to cathode rays with sunlike brilliancy—cold light par excellence—but unfortunately require too high a voltage for practical use.

Certain kinds of calcite acquire phosphorescence after exposure to sunshine or powerful ultra-violet rays, but show no fluorescence. Yet they glow with a clear orange-yellow luminescence under cathode rays, followed by a weaker phosphorescence of the same color.

It is therefore fairly evident that although there is a wide physical difference between these exciting agents, the general luminescent phenomena provoked by them are of a common origin.

Electro-luminescence

The most powerful and striking manifestation of natural electro-luminescence is seen in lightning and the aurora borealis, although in the case of lightning it is questionable whether the flash may not be due, more or less, to incandescence.(1) If it produces nitrous or nitric acid from the air, it involves a process of combustion, the intensely high temperature of which may cause vivid incandescent light. The corona which plays around a conductor that is charged to a high potential is also a form of electro-luminescence at atmospheric pressure.

When electricity passes through a rarefied gas or vapor, a luminescence of more or less intensity is produced depending upon the nature of the medium and the amount of the current. The various forms of the Moore illuminating tubes using rarefied atmospheres of nitrogen, carbon dioxide, or neon, are included under this heading, and also the mercury-vapor lamp. Then for scientific and display purposes we have the various forms of the Geissler vacuum tubes.

In most of the foregoing cases a certain amount of heat is generated, which is an undesirable component and plays no part in the production of useful light.

Electro-luminescence may also be produced by friction; indeed it is only a little more than a century ago when the only apparatus known for illustrating electrical effects was the old "Frictional machine" with its accompanying "Leyden jar." The noisy and vivid sparks from the latter were likened to miniature thunder and lightning by scientists of that day, although it remained for the intrepid genius of Franklin to prove beyond dispute the identity of these phenomena.

Thermo-luminescence

Certain varieties of calcite, fluorite, and other mineral compounds will glow in the dark when heated, and thus appear to contradict "Stokes' law" which maintains that, in fluorescence, the ethereal waves which produce light are changed from a higher to a lower frequency. On further consideration, however, this apparently anomalous behavior may be explained.

If phosphorescent zinc sulphide is exposed to any strong light and then viewed in darkness, it will be seen to glow with a phosphorescent light which will gradually fade away completely. If it is now heated (still in darkness) to say, 75 or 100 deg. C., it will become luminous again, and then again fade to darkness although the temperature is maintained. If the heat is now increased to 150 or 200 deg. C., it will once more light up, and again gradually become dark. If it is now allowed to become quite cold (still in darkness), a subsequent heating to 100 or even 200 deg. C. will not develop any luminescence; but if the heat is raised to more than 200 deg. C. it may or may not show light.

These observations appear to indicate that the rise above room temperature simply liberates a faculty which was previously *dormant* at the lower temperature, and that the low-frequency heat waves, per se, are not the actual exciters of luminescence.

In a different class, however, are those compounds (chiefly of the rare earths) which, when heated to incandescence, emit a light that is vastly brighter than that of a black body, such as carbon, at a similar temperature.(2)

Prominent in this class, because of its great industrial value, is the Welsbach gas mantle, which, by reason of the selective property of the rare earths in its composition, emits a light of great intensity. The light of the Nernst filament lamp is also in this class, and also the light emitted by burning magnesium.

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(1) *Revue Generale de l'Electricite*, Vol. XVI, No. 13, pp. 494-496.

(2) There is some difference of opinion as to whether the vivid light of the Welsbach mantle and other similar illuminants may be due to luminescence caused by the selective radiation of the rare earths, or to incandescence due to very high temperature induced in some way by a more rapid and intense combination of the flame gases within the pores of these oxides. The writer believes, however, that the weight of evidence now known is in favor of luminescence.

A discussion on this subject may be found in "Radiation, Light and Illumination," Lecture V, "Temperature Radiation," pp. 91-93 (Steinmetz, 1910).

Pyro-luminescence

The term "Pyro-luminescence" has been given to the light emitted by flames insofar as this is not due to the incandescence of solid particles.

If a metallic salt is introduced into a flame it will be vaporized and, if the flame is naturally colorless as in the case of burning pure hydrogen or alcohol, it will be colored according to the nature of the salt used. Thus sodium chloride will color it yellow, and copper chloride will make it green.

Spectroscopic examination of the colored flame will show the characteristic bright lines of the element superposed on the weak continuous incandescent spectrum of the original flame.

In the various kinds of electric arcs the light which they emit is caused partly by luminescence and partly by incandescence. In the carbon arc, for example, the component of incandescent light is largely in excess; whereas the light of some of the flame arcs may be mainly due to pyro-luminescence.

Chemi-luminescence

Chemi-luminescence covers a very wide field, as it includes the phosphorescence of animate as well as inanimate objects.

The firefly and the glow-worm are familiar examples of animal luminescence, among a host of others that are well known to naturalists. In all cases, the luminescence of living creatures is found to be due to the constant or intermittent oxidation of an animal secretion which has been named "luciferine."

Dr. E. Newton Harvey, of Princeton University, has made a long and careful study of animal light.(3) He discovered the marine crustacean "Cypridina" which lives in Chinese and Japanese waters. These minute creatures show a remarkably strong phosphorescence of a beautiful azure blue. If they are dried quickly and reduced to a coarse powder, they can be preserved for an indefinite time in a dry, well corked bottle. A few grains of this powder dropped into a small bottle containing some tap-water will, on being shaken up, shine like little blue stars, and their light will last for several minutes. It is the air contained in the tap-water that furnishes the necessary oxidizing agent, for water from which the air has been expelled by boiling will not produce good results. This experiment proves that the light is of purely chemical origin, and independent of any life principle.

Many kinds of bacteria are also phosphorescent, and the glow that is occasionally seen in decaying wood, sometimes termed "fox-fire," and also in certain kinds of fungi is believed to be caused by light-giving bacteria.

Luminescence may also be induced by chemical action in re-agents which have had no immediate living antecedents.

The well known glow of phosphorus, when exposed to the air, also comes under the present heading, being caused by the slow oxidation of the element.

Tribo-luminescence

Certain substances show sparklets of light when pulverized in a mortar or scratched with a sharp pointed instrument, and the term "Tribo-luminescence" has been given to this peculiar property. It may be illustrated in a very simple way by rubbing together the flat surfaces of two lumps of sugar in the dark, when a white glow will be seen at the points of friction. Some samples of natural minerals, such as apatite, leucophane, hexagonite, willemite, dolomite, pectolite, quartz, etc., are responsive to friction in this way, and so also are many artificial compounds. Of the latter, the manganiferous sulphide of zinc may be mentioned as being particularly sensitive. If a little of this compound in powder is put on a piece of cardboard and rubbed with the flat of a knife blade, a stream of yellow scintillations will be produced. Also if a solid lump of this compound is scratched with a sharp instrument *under water*, it will still emit flashes of light. Crystals of uranyl nitrate also show sparkles of light when shaken in a dry bottle.

SUMMARY(4)

A summary of the foregoing effects, as produced by some of the more susceptible substances and active radiations, is presented in Table I.

A consideration of these and other methods for producing a purely "cold light" suitable for general illumination does not present any promising outlook.

An improvement in our existing incandescent lamps, possibly something like that which was effected in gas lighting by the Welsbach mantle, appears to be more probable; but any method that would involve a

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(3) "The Nature of Animal Light," by E. Newton Harvey, Ph. D., published in 1920 by J. B. Lippincott, Philadelphia and London.

(4) A large number of institutions and individuals in this and other countries have done much valuable work in adding to the general knowledge of luminescence, but a list of their names and description of their accomplishments would be too long to record in this article.

TABLE I

SOME GOOD EXAMPLES OF LUMINESCENT EFFECTS

Class of Luminescence	Substance	Source of Excitation	Fluorescent or Phosphorescent	Color	Duration of Phosphorescence
Photo	Manganiferous cadmium phosphate	Disruptive spark between iron points	F and P	Red, orange, or yellow, according to preparation	Brief: a second or two
	Cadmium phosphate (pure)	Ditto	Ditto	Pure white	A few seconds
	Willemite or zinc silicate	Ditto	F and sometimes P	Bright green	Variable
	Calcium salicylate and other salts of salicylic acid	Ditto	F only	Bright blue	None
	Preparation of calcium sulphide (Balmain's luminous paint)	Mercury-vapor lamp; carbon arc lamp; sunlight, etc.	F and P	F pale lavender P bright blue fading to white	Very persistent, sometimes several hours
	Specially prepared zinc sulphide	Any bright light	Ditto	Different colors, red to blue, commonly yellow and green	Varies with quality, sometimes 30 minutes
Cathodo	Calcined coral Calcined egg shells	Cathode rays in vacuum tube	Ditto	Various colors, sometimes iridescent	Variable from a fraction of a second to longer
	Kunzite and calcite	Ditto	Ditto	Bright yellow	Several minutes
Electro	Gases and vapors at different pressures	Electric current	F only	Line and band spectra of various colors	None
	Mercury vapor lamp	Ditto	Ditto	Line spectrum, green predominant	Ditto
Thermo	Welsbach gas mantle	Gas flame	F	Varies with time of burning, yellowish to yellow-green	Ditto
	Calcite, fluorite, and many other natural minerals	Hot plate	Ditto	Various colors	Ditto
Pyro	Sodium chloride	Alcohol or gas flames	F only	Line spectrum, yellow predominant	Ditto
	Copper chloride	Ditto	Ditto	Line and band spectrum, green predominant	Ditto
	Carbon impregnated with metallic salts, magnetite, etc.	Used in lamps for general illumination	F*	Various shades of yellow to white	Ditto
Chemi	Glow-worm or fire fly	Oxidation of luciferine	P	Yellow-green	Continuous or intermittent
	Cypridina, and many other marine organisms	Ditto	Ditto	Blue	
	Phosphorus	Gradual oxidation	Ditto	Whitish	Continuous
	Decaying fish and wood	Luminous bacteria	Ditto	Ditto	Ditto
Tribo	Manganiferous zinc sulphide	Mechanical friction or abrasion	F	Yellow and orange	None
	Lump sugar	Ditto	Ditto	Whitish	Ditto
	Uranyl nitrate	Ditto	Ditto	Green	Ditto
	Many natural minerals, such as apatite, willemite, quartz, etc.	Ditto	Ditto	Various colors, chiefly orange and yellow	Ditto

* Combined with incandescence.

radical change in our present production, distribution, and supply of electricity would necessarily make slow progress.

Of *photo-luminescence* and *cathodo-luminescence* there is little to be said outside of their interesting scientific applications.

Possibilities of increased usefulness may be discovered in connection with *electro-luminescence*, providing that our present low-voltage lighting current can be made available, as in the case of the mercury-vapor lamp and recent forms of neon lamps, but any wider departure from white light than that shown by our present incandescent lamps would be found not generally acceptable.

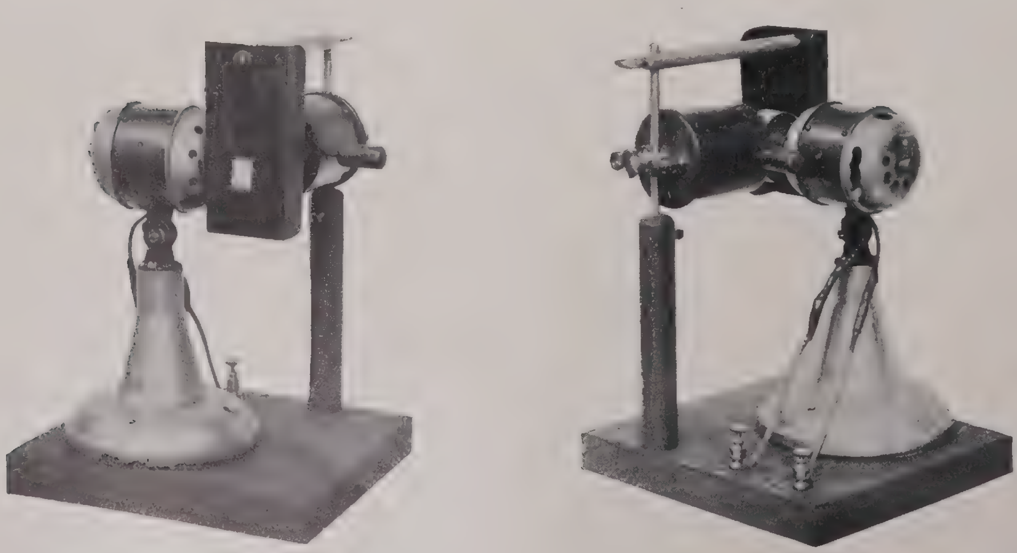
In the case of the Welsbach mantle which comes under the heading of *thermo-luminescence*, this may be said to have proved the salvation of what would otherwise have become a decadent industry in the field of artificial lighting.

Some future application of similar principles may possibly lead to increasing the efficiency of our incandescent lamps, as has been intimated.

One of the practical applications of *pyro-luminescence* is found in the flame arc, and it also renders invaluable service in spectrum analysis.

As far as *tribo-luminescence* is concerned, although it presents a very interesting scientific phenomenon, it is evidently quite out of the race as a source of illumination.

The possible developments in *chemi-luminescence* are fascinating but dubious. The organic constitution of luciferine is yet an unsolved problem, and it is idle to speculate on how it might be manipulated if the secret of its production is ever discovered. As the oxidation of this substance produces visible light, its subsequent deoxidation would make it available for use over and over again. This deoxidation might be accomplished electrically as shown by the experiments of Dr. E. Newton Harvey, and described in his book.(3) Any practical development of this method for producing light in the near future, however, appears to the writer to be improbable.



Two Views of the Phosphoroscope Developed by Mr. W. S. Andrews for the Convenient Determination of Some of the Phosphorescent Characteristics Exhibited by Many Luminescent Substances. It consists of an iron arc to produce the exciting radiations, a motor-driven short cylinder on the periphery of which is coated the substance under examination, and a window through which observations are made of the substance as it appears a brief interval after being excited.

Elevator Operation with Alternating-current Power Supply

By C. C. Clymer

Industrial Engineering Department, General Electric Company

When elevator service is required in a building located in a metropolitan or other district served by direct current, there is no excuse for using anything but direct-current elevator engines. When the building under consideration is located in a district wherein alternating current only is available, there are two alternatives open: (a) to convert the a-c. supply to direct current for use in d-c. elevator motors, or (b) to use the a-c. supply directly by means of a-c. motors. The conversion method is the choice where the highest grade of service is essential even at a higher cost for installation and operation. On the other hand, there is a very extensive field for a-c. elevator engines. The early limitations imposed upon equipment of this type, because of the unsuitability of the a-c. motors then available, have been overcome by the development of motors especially adapted to the purpose. These include induction motors of the single-winding and double-winding types, double-motor sets, and single-phase and polyphase commutator motors. The capabilities and limitations of each are outlined in detail in the following article.—Editor.

Electric elevators may be driven by either of two forms of engines; viz., the gearless or the geared types. In the former case the motor shaft carries the sheave or drum, and thus the total weight of the car, sling, cables, cage, compensating chains, counterweights, etc., is carried by the motor bearings, Fig. 1. In the other case, the sheave or drum is carried on separate bearings and the motor is connected to the drum shaft through suitable gearing, Fig. 2.

The first engine is of course driven by a very low speed motor, and the second type by a relatively high speed motor. Only direct-current motors have been successfully applied to gearless work, as the motor speed is usually around 65 r.p.m. and only very rarely reaches a speed of 150 r.p.m. This fact, coupled with the necessity for operating at greatly reduced speeds under both motor and generator action, has prevented the application of alternating-current motors to this type of machine. Alternating-current motors have been applied with complete success to the second type of drive as speeds around 900 r.p.m. are common, and speeds of 1200 r.p.m. are not unusual.

When the elevator engine is driven by a direct-current motor with an alternating-current power supply, a conversion of the energy from alternating to direct current is necessary. Three methods of accomplishing this result are now in use. These methods are in reality forms of control, since the same type of converting apparatus is used in each case; viz., motor-generator sets. The first case considered will be a motor-generator set furnishing direct current to a power circuit handling one or more elevators. The elevator motors proper are to be operated by the well-known rheostatic-control method wherein resistance is short circuited out of the armature circuit by means of magnetically controlled switches or contactors. With this type, reduced speed operation is obtained by means of shunted armature points or by variation of the shunt field of the motor, or a combination of both.

The second type is a slight modification of the foregoing in that a number of generators are permanently connected in series, thus providing a number of permanent voltage steps, the number of steps depending of course on the number of generators used; the usual number being four. Contactors are used as before to connect the elevator motor to successively increasing voltage steps; shunted armature points, field control points, or a combination of both being used when necessary. As before, any number of elevators may be driven from these multi-voltage buses.

The third type makes use of the well-known Ward-Leonard control system. This system in elevator control is known under such trade names as "Uni-Multivoltage," "Variable Voltage," "Generator Field Control," and "Generator Voltage Control." The control requires a generator for each elevator. Occasionally two generators are driven by one motor making a three-unit set, such a set taking care of two elevators. Usually each elevator has a separate motor-generator set and thus is entirely independent of the others in the building. This seems to be the most desirable arrangement as it tends toward greater continuity of service. With this type of control only the field current of the generator need be handled by the control contactors, which greatly simplifies maintenance work, and reduces maintenance expense in that the contactor tips last much longer and are considerably cheaper.

The Ward-Leonard type of control, when properly equipped with the latest appliances to secure accurate speed regulation, provides the highest type of elevator operation obtainable. This system of control is entirely independent of the power supply even when considering such factors as first cost, operating characteristics, maintenance, and power consumption.

The foregoing methods of operating electric elevators from an alternating-current power supply do not present engineering difficulties, due to the type of energy supplied, for their operation is identical in every respect to that where direct current is supplied by the central-station company.

When the number of elevators in a given building is small, and the elevator operation desired is not of the highest or Ward-Leonard type, it becomes rather expensive to purchase converting equipment, and unless the elevator or elevators are in constant service the standby or running light losses of the converting equipment become excessive. It therefore becomes very desirable for the building owner or operator, when this class of service is considered, to use an alternating-current motor directly on the elevator engine. The application of this type of drive has presented rather serious difficulties in the past, and many erroneous conceptions are held with regard to the operation of this type of equipment as manufactured today. The remainder of this article will therefore describe in detail the characteristics of alternating-current motors suitable for elevator work, and will indicate in a general way how such machines may be applied in order to secure satisfactory operation.

The earlier elevators were of the direct-current type due primarily to the facts that alternating-current motors were not very well understood, and that the direct-current motor was the only type with characteristics which even approached the requirements of elevator service. Other factors which tended to bring about this condition were: the large number of buildings generating their own power (which without exception was direct current), and the early power distribution by central-station companies being largely direct current.

The rapid growth of our cities so greatly increased the power demand that distribution by means of direct current became difficult and expensive. The difficulties in the way of direct-current distribution are well known; and except in a few of our largest cities, where this system became too extensive to permit any change before alternating current became popular, direct current is not available. Coincident with the difficulties of obtaining direct current came an increased land value making higher building not only desirable but an economic necessity. High buildings are useless unless the higher floors are readily accessible in point of time from the street. Another contributing feature toward higher buildings was the substitution of steel frames for brick bearing walls, which removed engineering difficulties as far as building height was concerned. These factors tended to increase the elevator load greatly and as central-station power became very popular elevator builders began to cast about for a satisfactory alternating-current motor for low- and medium-speed elevators to provide a type of service similar to that obtained with direct-current motors where Ward-Leonard control is not used.

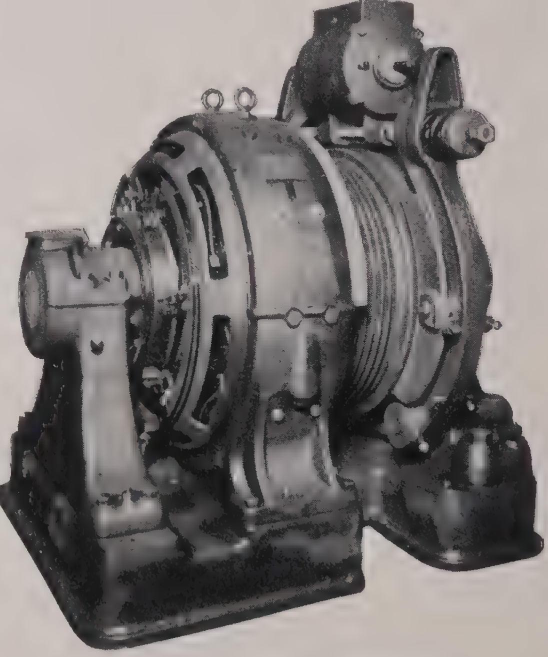


Fig. 1. Gearless Traction Elevator Engine

Requisites of Drive

The primary qualifications of any elevator drive, arranged in order of their importance, are:

(1) Reliability and safety
(2) Speed control
(3) Quietness of operation
(4) Smoothness of operation or riding qualities
(5) Power consumption.

The general-purpose alternating-current motor when measured by these standards will be found wanting on a majority of the counts, and cannot be favorably considered for elevator use. Induction motors, while without doubt the most reliable of all types, are fundamentally inclined to be noisy. This noise, if present, while perhaps of no great volume, has such strong penetrating power that it may be heard throughout an entire building. This is due usually to magnetic vibrations which may have a frequency equal to that of the power supply or they may be a multiple of it. There seems to be a strong tendency for these vibrations to be transmitted to the steel structure of the building. Also, the motors are usually placed at the top of a covered elevator shaft, which produces a pipe-organ effect, and this has been one of the most difficult obstacles to overcome in applying alternating-current motors to this type of service.

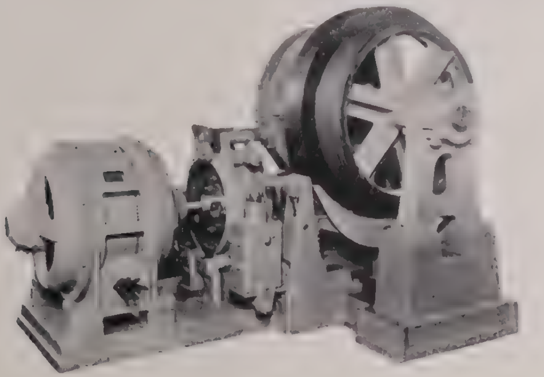


Fig. 2. Geared Traction Elevator Engine with Alternating-current Motor

The noises are usually more pronounced when there are high densities in the leakage paths of the magnetic circuit. Hence, such machines may emit a very objectionable noise during starting or when driven above synchronous speed. Noise may also be caused by windage, and although this may be objectionable it does not have the penetrating power of magnetic noises. Windage noises do not constitute an insurmountable difficulty as proper arrangement of the pent house, i.e., cutting off any direct air passages to the building proper, usually produces a quiet installation. Magnetic noise on the other hand may not seem objectionable in the pent house, but will be transmitted to remote parts of the building to such a degree as to render such sections of the building untenantable. Careful design has eliminated these noises to the point where they no longer prohibit the use of alternating-current motors for the most exacting service when high speeds are not required.

Smoothness of operation has also presented another difficult problem and here again the general-purpose motor has been found wanting, and recourse to special design found necessary. The alternating-current motor is inherently a constant-speed device, and does not lend itself very readily to adjustable-speed work or to applications which require constant starting with heavy loads, such as are presented by elevators or hoists. The ability to produce high starting torque is one of the requisites of an elevator drive. Once the elevator has been accelerated, a comparatively small amount of power is required to keep it in motion. A number of tests have indicated that geared equipments require about 200 per cent as much torque to start a load as to hoist it. The reasons for this excess torque are that static friction is greater than running friction, and that on standing the oil is squeezed from the bearings and from between the worm and gear, etc. Coupled with these difficulties there is likely to be some voltage variation at the motor under starting conditions, and as the available torque varies as the square of the applied voltage it is desirable to use a starting torque of 250 per cent of the torque required to keep the elevator in motion when hoisting full load. This refers to the rated load of the elevator. Thus a motor to be suitable for elevator service must be capable of developing 250 per cent of its rated full-load torque. As mentioned before, this refers to the elevator when hoisting its rated load. This condition does not apply to a partially loaded car since under this condition the car may be so lightly loaded as to be overhauled by the counterweight, thus with the application of 250 per cent torque the car would accelerate so rapidly as to be very objectionable to the passengers. Therefore, it is necessary to incorporate some feature in the control which will reduce the torque at starting and increase it by such increments as will not jerk the car regardless of the loading. This may be accomplished by some form of primary or secondary resistance whose steps are governed by time-limit or current-limit devices.

Experience seems to indicate that time-limit gives more desirable characteristics.

Experience also indicates that the rate of change of acceleration is more important than the rate of acceleration, since it is possible for most people to support themselves under an acceleration which increases their weight 33 per cent provided this force is gradually applied; however, applying this force instantly would throw most persons to the floor. This force corresponds to an acceleration of approximately 10.7 ft. per sec. per sec. Now if the rate of acceleration of a car is gradually increased to this value and then gradually reduced to zero, a very high car speed may be reached in an extremely short time without undue discomfort to the passengers. To explain this mathematically is to state that the third derivative of space with regard to time is $\frac{d^3s}{dt^3}=C$ where acceleration is expressed as the second derivative of space with regard to time or $\frac{d^2s}{dt^2}$. This subject has been thoroughly covered in an article by Basset Jones.(1) Thus, it is the sudden application of large amounts of torque that is objectionable rather than high rates of acceleration. Hence, it is desirable to limit the rate of application of torque by time rather than by current since by current limit it is possible to change the rate of acceleration between wide limits. Also, with the alternating-current motor, current plotted against torque is not a straight line but rather a curve due to the effect of power-factor changes.

Another serious objection to current-limit acceleration is the difficulty of arranging for the proper starting of lightly loaded cars. Thus, if the current-limit relay is set low so as to produce a fraction of the torque required to start the maximum load, it is not possible to start the car when fully loaded as the accelerating contactors would be locked out. With time-limit devices, however, low-torque points may be provided and maximum torque will be applied in a predetermined time. This provides a smooth start for the lightly loaded car, and also assures sufficient torque for the maximum load.

Satisfactory operation may be obtained by a combination of time- and current-limit acceleration, i.e., by using time limit on a number of the first points and current limit on the remainder. The only advantage of this latter method is the reduction of the current peak when handling maximum load. This is not especially desirable when quality of service is considered, since a roughly operating car is likely to be the result under average service conditions. Acceleration which is a function of time, rather than a function of current, seems to be the most desirable type for elevator service.

There are two ways of gaining a smooth start; viz., putting in a sufficient number of resistance steps so that incremental torque applications are sufficiently small to give smooth acceleration, or by increasing the WR^2 of the motor rotor or parts located on the motor shaft. The second method has the disadvantage of greatly increasing the power consumption as well as slightly increasing the first cost of the equipment. Of course, there is always a certain amount of WR^2 present in the elevator motor, brake wheel, and elevator equipment proper. However, on the usual alternating-current elevator installation the WR^2 of the elevator proper referred to the motor shaft is small compared to the motor rotor. The net result is that the average alternating-current elevator motor may be accelerated by a three point control when the car speed does not exceed 150 ft. per min.

Another complication is caused by the fact that elevator loads often overhaul the motor so that while resistance can be cut in to slow down the car speed to assist in making accurate landings when hoisting a loaded car, lowering a loaded car and cutting in resistance may tend to speed up the car and make the landings more difficult. This means that for single-speed alternating-current motors the car switch can have but one point for each direction of travel. Thus, if more than one car speed is desired, it is necessary to provide a motor having more than one synchronous speed. With such a motor, the car switch may have as many points as the driving motor or motors have synchronous speeds. The most desirable landing speed is around 60 ft. per min. for high-grade passenger service. On freight elevators this may be as low as 10 ft. per min. when there are tracks to level up. It must be realized that these values are more or less debatable and are governed by local conditions. Trained operators have been able to give good service at landing speeds as high as 200 ft. per min. It is generally accepted, however, that for exacting passenger service 140 ft. per min. is about the limit. Therefore, if higher elevator speeds are required there must be some means of providing a positive reduced speed around or below 140 ft. per min., with moderate variations, regardless of whether the motor is driving or being overhauled.

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(1) "Time-velocity Characteristics of the High-speed Passenger Elevator," General Electric Review, Feb., 1924, p. 111.

Types of Suitable Induction Motors

There are three ways of accomplishing the foregoing result, as follows:

First, by building a motor having one stator winding but arranged for speed changing by changing the number of poles by regrouping the winding. The only available motor of this type is limited to a 2:1 speed change.

Second, by building a motor having two separate windings in the same slots on the stator and sequencing through these windings. The ratio of speed change with this type is limited only by physical laws and by the ability of the designing engineer.

Third, by building a double-motor set having two separate motors included in the same frame. The two rotors are mounted on the same shaft and this shaft is supported by two end-shield-supported bearings. The motors however are electrically independent. Here again the ratio of speed change is limited only by physical laws and by the ability of the designing engineer.

The advantage of the first type of motor lies in the fact that it has a smaller diameter since it uses all of the material at both speeds. It also has a smaller WR^2 which means lower energy consumption, less wear on the brake mechanism, and has greater ability to radiate its losses due to the fact that there is not an idle winding through which the heat will have to pass. Should repairs become necessary on the windings there is only one winding to disturb, whereas with the second type should the bottom winding fail the other winding must be taken out and replaced as well, also a burnout in one winding is almost certain to damage the other. The first type, however, has the disadvantage of being limited to a 2:1 speed ratio which limits it to elevators whose speed does not exceed about 300 ft. per min.

There has been some criticism of motors of this type which require one pole grouping to be disconnected before the other is connected to the line. It has been stated that control of the elevator is lost during this period. This criticism is not based on facts. The condition is purely and simply a control problem, and is no more pertinent to motors of this type than to those with the double-winding, where both windings may be energized during the transition period. The criterion of this point is practice. Hundreds of the single-winding two-speed motors have been operating for years in elevator service, and a single instance of trouble of the foregoing nature, due to the type of winding, is yet to be reported. When speed ratios greater than 2:1 are required, the double-motor set or double-winding motor should be used, for while pole regrouping with a single winding is possible for speed ratios other than 2:1, such regroupings are complicated and involved, resulting in an impractical and expensive motor.

The single-winding motor (assuming it is of the squirrel-cage type) has a high-resistance rotor which lowers its efficiency, gives poor speed regulation, and increases its heating. This also applies to the second type when a squirrel-cage rotor is used.

The advantage of the second type over the first type lies in the fact that it allows the car speed to be increased in the ratio of the two speeds. (A ratio as high as 6:1 has been used.) Its disadvantage lies in the facts that all the material is not active at all times, the ability of the motor to dissipate heat has been decreased, repairs to stator are difficult, and the design of the motor is generally a compromise between the two ratings. The WR^2 of the rotor is larger than that of the first type having a 2:1 single winding.

The third type allows each motor to be especially designed for its particular requirements, the high-speed motor can be designed with a wound rotor for maximum efficiency and minimum slip. Motor heating is thus reduced and speed regulation on the high-speed end is greatly improved; also if a slip-ring motor is used on the high-speed end smoother acceleration and reduced line disturbances on the power supply result as the static friction is broken and the elevator car put in motion by the squirrel-cage motor. Due to the distribution of the windings a smaller diameter of rotor is usually permissible, which of course reduces the WR^2 very materially.

With motors or motor sets of the double-speed type, the elevator is usually started on the low-speed winding and after accelerating to the first-speed point the motor is thrown over to the high-speed connection and the elevator travels at full speed. On stopping, the control as usually arranged automatically throws the elevator on the low-speed motor, sequencing through a suitable primary resistance for a definite predetermined time. This provides a suitable landing speed as well as returning energy to the line, thereby greatly reducing the duty of the brake wheel.

Some controls have been built which utilize the low-speed motor only to slow down, the starting being done on the high-speed motor. This does not appear to be as satisfactory from the building owner's point of view for the power required from the line to produce a given torque is a function of the motor speed. Hence, if a 3:1 speed ratio is used, almost three times as much power will be required at the initial start on the high-speed motor as on the low-speed motor. This means increased power consumption and poorer line regulation, and considering the number of starts the average elevator makes a day (around 2300) this power consumption may readily become appreciable.

When alternating-current motors were first considered for elevator service, two types were available; viz., the slip-ring type, and the squirrel-cage type with low-resistance rotor. The slip-ring motor seemed to have the most desirable characteristics inasmuch as it produced a much greater starting torque per ampere than the squirrel-cage motor did. Also, a more uniform acceleration could be secured by varying the resistance in the rotor circuit, as well as allowing a more flexible control equipment. The slip-ring motor also produced less disturbance on the building lighting circuit, which is a very important consideration and caused the central-station companies to look with considerable disfavor on the cage-wound rotor. Later developments have more or less reversed these conditions. The fundamental difference between a motor with wound rotor and a squirrel-cage motor, as to starting torque, is that the wound rotor must be wound for a definite number of poles. This divides the rotor into certain definite magnetic paths whose position depends on the position of the rotor. Under fully saturated conditions these rotor sections have certain favorable and unfavorable positions with regard to the stator. The rotor pole and stator pole give their maximum starting torque only when they are in the most favorable relative positions. Also, due to the polar winding the rotor has relatively long end connections, and this coupled with the fact that deeper slots are necessary with longer rotor teeth gives a much higher reactance for the wound rotor. The ratio of rotor teeth to stator teeth is not as flexible on the wound rotor as with the squirrel-cage rotor, with the result that this favorable or unfavorable rotor position, "position factor" as it is usually called, is very likely to be accentuated due to the change in reluctance of the magnetic circuit with different rotor positions. The squirrel-cage rotor on the other hand is not wound for any definite number of poles; hence if proper care has been observed in the design and shape of the teeth, this rotor has practically no position factor, and consequently produces as much torque in one position as in any other. Coupled with this, the end connections are very short, the slots are not as deep as on the wound rotor nor is insulation required on the rotor

TABLE I

	Squirrel-cage Motor	Wound-rotor Motor
Starting torque lb-ft. at 1 ft. radius	500	375
Maximum torque lb-ft. at 1 ft. radius	500	470
Full-load torque, 30 h.p.	200	185
Synchronous r.p.m.	900	900
Full-load speed	765	845
Starting current, amperes	245	280
$\frac{\text{Horse power}}{\text{Starting current}}$	0.122	0.107
$\frac{\text{Lb-ft. starting torque}}{\text{Amperes}}$	2.04	1.34
Per cent in favor of squirrel-cage motor	52	...
$\frac{\text{Lb-ft. starting torque} \times \text{full-load r.p.m.}}{\text{Amperes} \times \text{syn. r.p.m.}}$	1.73	1.26
Per cent in favor of squirrel-cage motor	37	..
Rotor WR²	47	54

bars, all of which result in a much lower rotor reactance. This means that a squirrel-cage motor of similar design in every respect to a wound-rotor motor with the exception of the rotor, which will be of the high-resistance type, will exert more starting torque in any position than the wound rotor will in its most favorable position. The net result of the foregoing fundamental considerations means that if the high-resistance squirrel-cage motor is properly designed, as much as 30 per cent more starting torque may be secured with the squirrel-cage motor than with the wound-rotor motor. Due to the better power-factor and the absence of the favorable and unfavorable positions, the starting torque per ampere will be much greater with the squirrel-cage motor than with the wound rotor. One other point favoring the squirrel-cage motor is the reduced WR^2 made possible by the absence of end connections, slip rings, insulation, banding wire, and less iron in the magnetic circuit. With two similar machines as outlined, the squirrel-cage motor will have about 10 per cent more slip with approximately the same input. Thus, if the motors are compared on a horse-power basis more torque is required of the squirrel-cage motor. This condition results in about a 10 per cent reduction in the advantage of the squirrel-cage motor, in other words the squirrel-cage motor has about 20 per cent advantage with regard to starting torque over the slip-ring motor.

Table I will demonstrate this point. The two motors are built in the same frame. The motors would not carry the same rating for elevator service as the slip-ring motor would have its rating reduced due to the low starting torque. Therefore, to make a proper comparison two motors will be compared which have approximately the same starting torque and thus would be suitable for the same elevator duty. These are listed in Table II.

There is one other consideration that may be of interest which takes into account the service that the elevator is to give. This is the fact that an elevator which is called upon to hoist its maximum load only occasionally will produce less line disturbance when equipped with a slip-ring motor than with a squirrel-cage motor. This is due to the fact that while the current which a squirrel-cage motor will draw from the line varies, as a close approximation, directly as the voltage, the torque varies as the square of the voltage.

Therefore, with 100 per cent torque the squirrel-cage motor will draw 63 per cent of its stalled current while the wound-rotor motor will draw but normal full-load current. This relation is shown in Fig. 3.

As a point of interest, the effect of using an unbalanced resistance in the primary of a three-phase squirrel-cage motor is included in Fig. 3; i.e., arranging the control with resistance in two of the lines only. This greatly increases the line current, the motor

TABLE II

	Single-speed Squirrel-cage Motor	Slip-ring Motor	2:1 Two-speed Squirrel-cage Motor
Starting torque lb-ft. at 1 ft. radius	410	440	520
Full-load torque (40 per cent starting torque)	164	176	208
Synchronous r.p.m.	900	900	900
Per cent slip	22	5	19.8
Full-load speed	712	855	722
Starting current, amperes	220	292	245
Full-load horse power	22.2	28.6	28.6
$\frac{\text{Horse power}}{\text{Starting amperes}}$	0.992	0.98	1.17
$\frac{\text{Lb-ft. starting torque}}{\text{Starting current}}$	1.86	1.51	2.12
Per cent in favor of squirrel-cage motor	23	..	40
$\frac{\text{Lb-ft. starting torque} \times \text{full-load speed}}{\text{Starting current} \times \text{syn. speed}}$	1.47	1.43	1.70
Per cent in favor of squirrel-cage motor	3	..	19
Rotor moment of inertia	35	65	52
Kilowatt-seconds consumed in friction on brake wheel when stopping motor from synchronous speed	6.5	11.75	2.5

heating, and the power consumption. Line regulation would be increased and the tendency toward disturbing the building lighting would be accentuated. This control scheme should of course be avoided.

Summarizing the effect of the foregoing on lamps, it may be said that whenever the wound-rotor motor starts a fully loaded elevator, the lights will wink worse than with the squirrel-cage rotor. This situation is reversed when a lightly loaded elevator is started. However, as the elevator will be called upon to start the maximum load only occasionally, the control may be arranged to require much less than the maximum starting current, so the average effect on the lights will be much less. The squirrel-cage motor will have the same inrush of current regardless of the load in the car when used without buffer resistors. With buffer resistors operation on reduced loads may be slightly improved. The only difference between a lightly loaded car and a fully loaded car will be in the duration of the peak, which may be as much as a quarter of a second. On any installation which taxes the voltage regulation of a given line to the limit, it seems safe to say that a given elevator may be geared to operate at a speed as much as 20 per cent above the speed of a similar elevator equipped with a squirrel-cage motor for equivalent effect on the lighting system when handling partial loads in the car. If the elevator is at all over-motored this effect is more pronounced. However, with an installation which is properly motored and which handles its maximum load rather frequently, such as in an office building for instance, the squirrel-cage motor seems to have the advantage.

As mentioned before, the starting amperes per pound of starting torque of an ordinary high-efficiency low-resistance-rotor squirrel-cage motor are far in excess of the permissible value for elevator service.(2) The introduction of resistance into the rotor of this type of motor increases the starting torque and lowers the starting current as well as lowering the efficiency. A certain given amount of resistance will produce the maximum torque at starting. This is the greatest torque that may be secured from a frame at a given speed. It does not, however, represent the maximum torque per ampere that may be secured from a given frame. Fig. 4 shows the characteristics of a certain motor with respect to speed, torque, current, and horse power. Just enough resistance has been added to this rotor to produce maximum torque at starting. It also shows the same motor with the rotor resistance increased so as to produce the maximum starting torque per ampere. This has resulted in a considerable sacrifice of output. The current rating of the motor covered by Curve No. 1, Fig. 4, permits an output of 109 lb-ft. of torque. This corresponds to a horse-power rating of 15.3. This motor will exert a maximum starting torque of 273 lb-ft. with 137 amp. or 2.00 lb. per amp. The normal rating corresponds to a running horse power of 0.115 per starting ampere. The motor covered by Curve No. 2, Fig. 4, will produce a running horse power of only about 6.67 due to excessive slip at any greater torque. This motor will produce a starting torque of 150 lb-ft. with a starting current of 65 amp., or 2.31 lb. per amp. It will exert 0.104 running horse power per starting ampere. It might appear from a superficial examination that this latter motor would have the most desirable characteristics in the ratio of 2.31 to 2.00. Investigating the problem further, if a starting torque of 273 lb-ft. is required, a motor if built along the lines of Curve No. 2 must be increased in size in the ratio of 273/150, and this means that the starting current

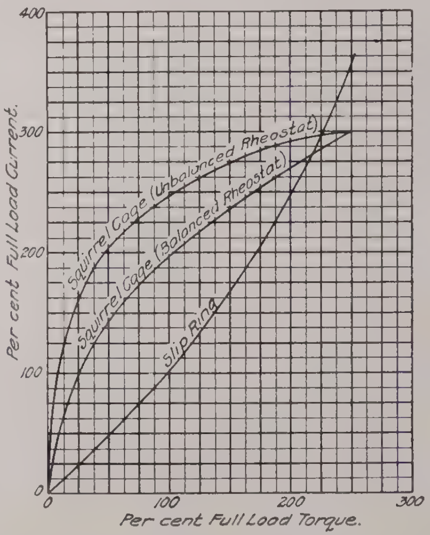

Fig. 3. Per Cent Full-load Current in Per Cent of Full-load Torque with Locked Rotor. The squirrel-cage motor has resistance in the primary, and the slip-ring motor has resistance in the secondary

must be increased in the same ratio or $65 \times 273/150 = 119$ amp. This motor, however, would have a horse-power output of only 12.1, which means that the motor would not drive an elevator which it would be capable of starting, so that on a horse-power basis, assuming identical characteristics on the large motor with reference to power-factor, etc., the motor size must be increased in the ratio of 15.3/6.67 and the starting current would become $15.3/6.67 \times 65 = 149$ amp. Thus there would result an increase of starting current and a great increase in motor losses due to the increase in slip from 18 to 34 per cent. Coupled with an increased WR^2 due to the larger motor, the power consumption would be very greatly increased, Increase in motor size means increase in cost so that this latter motor would have little to recommend it, and what apparently was an advantage would result in a great disadvantage.

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(2) "Characteristics of the High-resistance-rotor Squirrel-cage Motor for Elevator Service and Comparison with the Phase-wound-rotor Machine," by R. H. Mc[illegible]. GENERAL ELECTRIC REVIEW, Jan., 1916, p. 69.

It might be well to put in a word with regard to tests for torque on motors of this type as the rotor conductors have a high positive temperature coefficient. That is, if the motor were connected to full voltage for a period of eight seconds, the rotor temperature would have risen to a point where considerably more torque per ampere would be obtained at the start. Thus, the characteristics would approximate those of the motor covered by Curve No. 2, Fig. 4. As a matter of fact, these temperatures are not encountered in actual service conditions, so a false characteristic is shown. Therefore, if a motor of this type is to be tested it should be connected to a spring balance and locked at about the expected torque. Full voltage should be applied and the scale should be adjusted until balanced by the motor, caution being taken not to overheat the rotor by too frequent applications of voltage, but to maintain, if possible, average temperature conditions. The current should be read by an oscillograph. This shows the true value of starting current which would not be read by an ammeter but would show up as light flicker where voltage regulation was likely to be bad. Fig. 5 shows the length of time required for a squirrel-cage motor to come to full speed and shows why high rotor temperatures are not encountered in service conditions, as only 0.675 sec. are required to accelerate a motor to full speed when operating under rated load conditions.

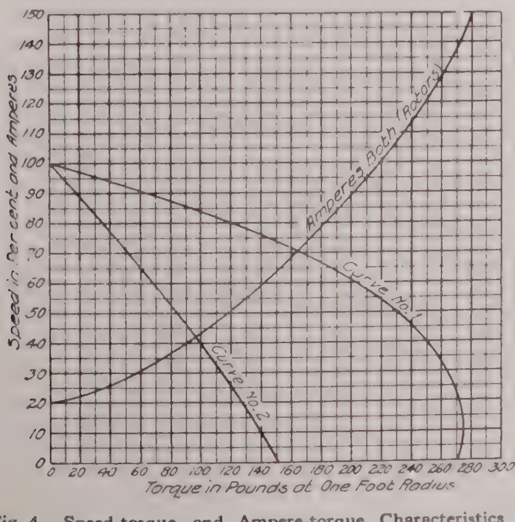

Fig. 4. Speed-torque and Ampere-torque Characteristics of High-resistance Squirrel-cage Induction Motors

Curve No. 1 Standard motor

Curve No. 2 Same motor with special high-resistance rotor to give high torque per ampere at starting

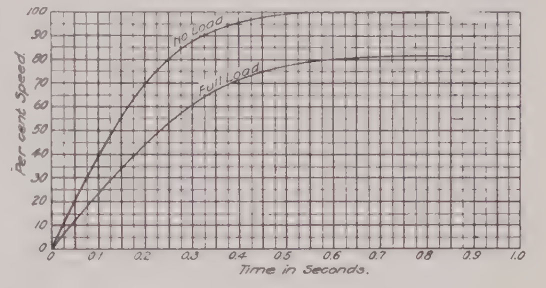

Fig. 5. Time Required by a Squirrel-cage Motor to Attain Full Speed When Operating Against Full Load and No Load; Full Voltage at Starting Being Applied to Stator in Each Case

A measure of motor performance may be obtained by using an ordinary dead-beat ammeter when several motors are compared. A motor having a small WR^2 will not produce as much deflection as one having a greater WR^2. This is as it should be as the motor giving the greatest deflection will produce the greatest effect on the lighting. Thus, a motor having a starting current of 200 per cent full-load current does not necessarily mean a desirable motor, but rather a motor which produces the greatest running horse power per starting ampere, the running horse power being based on 40 per cent of the starting torque. Also, the ratio of starting torque per starting ampere and the WR^2 of the rotor together with the slip at full load should be considered.

Thus a motor having the highest horse power per starting ampere, the highest ratio of starting torque over starting amperes, the lowest WR², and the lowest slip at full load is the best motor. A motor may not have all these points in its favor, hence a compromise may have to be made, but in order to make a choice something must be known of the conditions under which it is to operate.

From the foregoing it would seem that for a relatively high-speed installation, requiring a speed range of more than 2:1, the ideal arrangement would be to break the static friction and set the elevator in motion by a squirrel-cage motor up to the landing speed and finish the acceleration to high speed by a slip-ring motor. This as mentioned before would result in a cooler motor, give better voltage regulation, and provide smoother acceleration with less line disturbance.

While it is not the purpose of this article to go into elevator control, it might be well to cover motor characteristics which affect the control. The first point is motor WR². A motor having a large WR² gives the usual flywheel effect and assists in giving smooth acceleration, i.e., it reduces the tendency of the car to jerk when lightly loaded. However, it has the disadvantage of increasing the power consumption and increasing the power demand, which means that in installations which tax the regulation of the line the lighting disturbances will be accentuated. Thus, a motor with a cage-wound rotor having a low WR² may be accelerated in practically the same time with as smooth starting characteristics by the use of one or possibly two primary resistance steps. This motor with a rotor having a small WR² will also be much easier on the brake since the retardation of the motor armature constitutes the major portion of work of the brake on geared equipments.

With two-speed motors or double-motor sets the car is usually retarded by going from high speed to low speed for a predetermined time and then off. When the car is traveling at high speed and the low-speed motor is thrown on, the low-speed motor is operating at 200, 300, or 400 per cent synchronous speed, as the case may be, depending on the motor or set used.

With most designs of multi-speed motors, to drop directly from high speed onto the low-speed winding will give a severe jerk or bump which is very objectionable in the car, and objectionable to a degree depending on the magnitude of the bump. It is thus desirable to use a buffer resistance of one or more steps to reduce the torque change at the throw-over point. The behavior of the motor under this condition is of interest and Figs. 6 and 7 show the relation and torque with different values of primary resistance in the low-speed winding.

The values of speed, torque, and resistance are all expressed as percentages in order to make ready comparisons. One hundred per cent ohms was an arbitrarily chosen value to give a torque point in the neighborhood of full-load torque at standstill. The basic curve of the high-speed connection also assists in interpreting the curves. Fig. 6 shows a motor with rather good characteristics while Fig. 7 shows a high-resistance squirrel-cage motor not suitable for elevator service. Analyzing Fig. 7 it is found that a primary resistance which will provide 130 per cent torque at standstill will develop 1140 per cent torque when operating at 175 per cent speed. Thus, were the elevators operating on the high-speed winding developing around 85 per cent torque, and the control switches the elevator onto the low-speed winding with 100 per cent resistance in the primary leads of the low-speed connection, a torque change of 1225 per cent would be experienced. The application of this much torque would jar the car very severely with possible damage to the mechanical parts of the elevator. It is evident that considerable difficulty will be

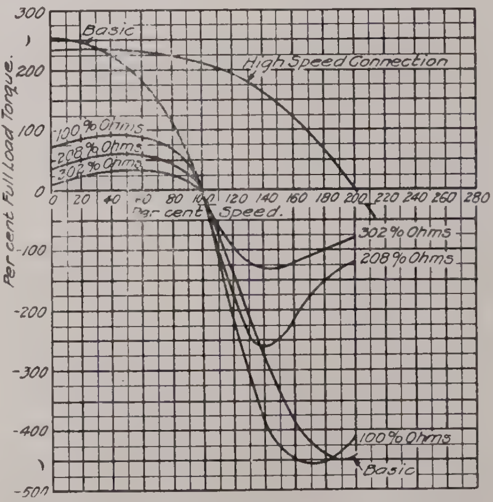

Fig. 6. Speed-torque Characteristics of a Two-speed 2:1 Squirrel-cage Motor Suitable for Elevator Service. The effect of varying the primary resistance is shown

experienced in getting a control which will provide satisfactory operation of such an equipment, unless considerable inertia is built into the motor rotor or brake. Even with 528 per cent ohms in the primary leads, 550 per cent torque will be exerted at 120 per cent speed. It is not possible to use any more resistance than this, since at the change-over point only 40 per cent of full-load torque is provided with 528 per cent ohms. A greater amount of resistance would hardly furnish sufficient torque at this point to retard the car, and with full load overhauling the car might actually gain speed in place of being retarded. Thus, whenever the car is retarded by the low-speed winding a severe jerk will be experienced when passing this point. This is due principally to the steepness of the torque curve both approaching and leaving the peak. This means that the rate of acceleration will be high, unless the WR² of the moving parts is great enough to overcome the objectionable effect. Thus, a winding which may be entirely suitable for low-speed work would not be at all acceptable if used for retarding service. The characteristics of the motor shown in Fig. 6 provide very desirable operating qualities for elevator service. A suitable resistance combination here gives ample retarding torque at the change-over point, and the torque does not become excessive any place along the torque curve.

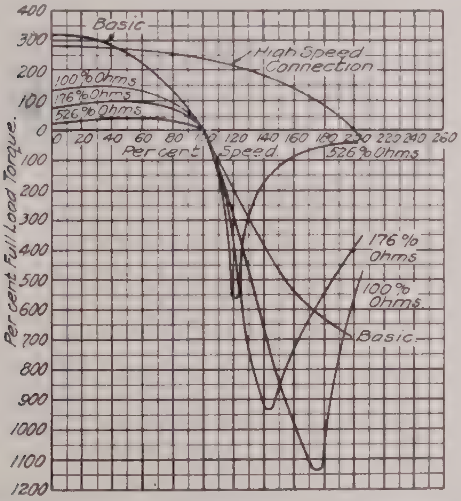

Fig. 7. Speed-torque Characteristics of a Two-speed 2:1 Squirrel-cage Motor, Unsuited for Elevator Service. The effect of varying the primary resistance is shown

Types of A-c. Commutator Motors

The motors covered so far have been of the standard polyphase straight-induction types. Two other types of alternating-current motors have been applied to elevator service; viz., single-phase motors, and polyphase-commutator motors.

Single-phase motors of the single-speed type which have met with any success in elevator service have been of the repulsion type using a commutator. The straight-repulsion type while providing good starting torque has series speed characteristics which make it unsuitable for elevator work. It is, therefore, necessary to modify the design by means of additional windings or to provide a mechanical device which will short circuit the commutator; this device to be operated by centrifugal force.

Ronald Grierson in "Electric Elevators for Modern Buildings," describes an elevator driven by a plain repulsion motor, the speed regulation being obtained by shifting the brushes. Repulsion motors are very sensitive to brush position and the installation includes a mechanical device which shifts the brushes so as to maintain constant speed. Thus maximum torque will be exerted until rated speed is reached whereupon the governor will shift the brushes until the motor torque will just balance that required by the elevator. Mr. Grierson makes no reference to the behavior of this motor under overhauling load but apparently it is accomplished by shifting the brushes to a point where the motor torque is reversed.

It would seem to be more desirable to accomplish this result electrically by the addition of another winding on the motor. Motors of this type are now available which produce the required torque and which have very good speed regulation. These machines will produce about 1 lb-ft. torque per ampere at 220 volts. This particular motor has a full-load speed of 1760 r.p.m. and a maximum torque of 18 lb-ft. This corresponds to a horse power of 2.4 and the horse power per starting ampere is around $\frac{2.4}{18} = 0.133$.

The field of application of single-phase motors seems to be limited to small isolated installations where polyphase power is not available. They are more complicated and due to their commutators are not so rugged as the polyphase type. They are seldom considered for installations requiring more than 10 h.p.

Polyphase adjustable-speed commutator motors have been applied to elevator work in Europe and have some very desirable characteristics. Fig. 8 shows the speed-torque characteristics of such a motor. Speed control is obtained by shifting the brushes. This motor has suitable regenerative ability when operated above its adjusted speed. It also has shunt characteristics, hence no governor is needed to maintain the rated speed. The control consists of reversing contactors and a brush-shifting device for speed control.

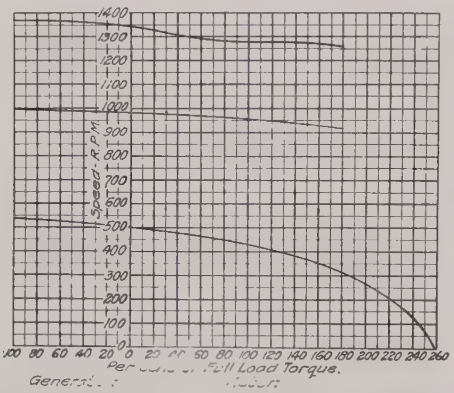

Fig. 8. Speed-torque Characteristics of a Brush-shifting Alternating-current Motor

This motor will develop 250 per cent starting torque with 189 per cent full-load current. It is rated 42 h.p. at 1285 r.p.m. and 14 h.p. at 430 r.p.m. Thus, on a 220-volt circuit, full-load current will be approximately 100 amp. with 196 amp. at starting. Thus, the ratio of starting torque over starting current is $\frac{430}{196} = 2.19$. The ratio of horse power over starting current is 0.214. The slip is 3.8 per cent and the WR^2 is 75 lb-ft. This motor compares very favorably with the 3:1 induction motors, and the control as represented by magnetically operated contactors is much simpler. The brush shifting mechanism, however, becomes complicated and more or less hard to maintain. Its main advantage lies in the smooth torque changes it provides when operating over its 3:1 speed range. Any number of intermediate speeds may be obtained over this range and the speed regulation is exceptionally good, being the equal if not better than that obtained from the direct-current motor without special speed regulating devices. The intermediate speed points are obtained by simply shifting the brushes. The speed with which the brushes are shifted determines the rate at which the elevator will be accelerated or retarded. Torque changes are thus made in increments rather than abruptly over the accelerating period, thus there is no abrupt change in the speed-torque curve such as is inevitable with the usual rheostatic control which cuts out blocks of resistance at each step.

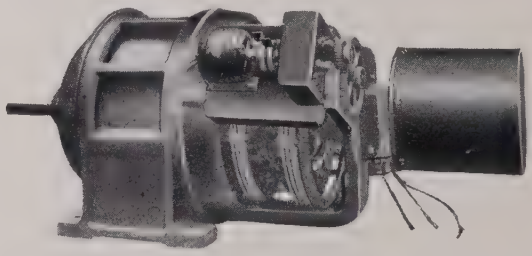

Fig. 9. Variable-speed Brush-shifting Alternating-current Motor Having Shunt Characteristics

Motors of this type have been built in this country, Fig. 9, but so far have never been applied to elevator service due to the complication involved by the brush-shifting mechanism. They have, however, found some application in Europe for elevator service.

Recent Developments in High-frequency Inductive Heating

By Dudley Willcox
Ajax Electrothermic Corporation

In our issue of November, 1922, Dr. Northrup explained the principle of electric heating by ironless induction and its application to melting materials, to heat treating steel, and to heating large steel masses to moderate temperatures. For these purposes the only source of high-frequency energy then used was a special circuit made oscillatory by a discharge gap and proper values of capacitance and reactance. As a superior alternative to this source of high-frequency energy for the larger capacity furnaces, there has recently been developed an alternating-current generator that differs from a standard alternator only in those respects which enable it to deliver the requisite high-frequency current. Combinations of ironless-induction furnaces with this new form of energy supply are described in the following article. Editor.

High-frequency currents have been applied to melting and heat treating operations on a laboratory scale for seven or eight years. Commercial installations have been made for producing alloys of nickel-iron, gold-platinum, osmium-iridium, and other metals which require high temperatures, freedom from contamination, and thorough mixing. High-frequency furnaces are also used commercially for melting metals of the tungsten group in graphite containers for producing carbides. The potential uses of such furnaces for other purposes are numerous.

In principle, the high-frequency furnace is a special transformer in which the primary is a coil of copper conductor and the secondary a mass of conducting material within the coil. Many lower frequency induction furnaces have been designed on the principle of an iron-core transformer in which the secondary is a loop of molten metal. These also differ from the high-frequency furnace in respect to the amount of radiating surface and in features of operation and maintenance.

The high-frequency furnace may have a bath in the form of a cylinder which has small radiating surface for a given volume. The metal bath may be contained in an ordinary crucible. The current in the primary does not heat the coil much above room temperature, but the mass within the coil is rapidly heated to the melting point, and higher if desired. As in ring-type induction furnaces, the metal is stirred by electro-magnetic forces so that the thorough mixing of alloys is assured.

The usual form of high-frequency current "Converter" consists of a reactance, a step-up transformer, a special form of discharge gap, and a bank of condensers. By this combination, current from 60-cycle power lines is changed to oscillatory current having the frequency which is the natural period of the furnace circuit. A high-frequency converter and a small furnace operating from it are shown in Fig. 1.

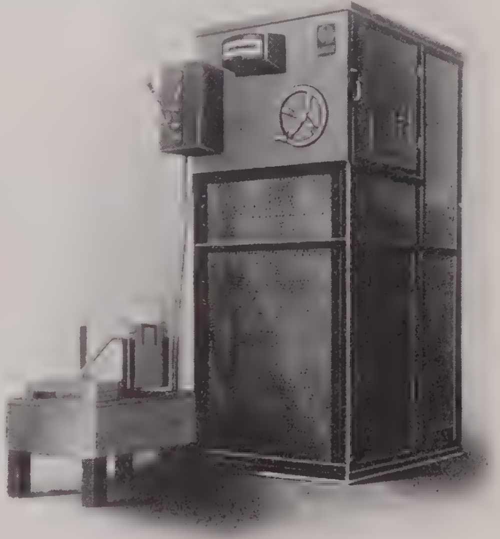

Fig. 1. A 20-kw. High-frequency Converter and Small High-temperature Furnace Installed in a Laboratory

Fig. 2 shows a high-frequency furnace operated from a rotary high-frequency generator. Fig. 3 shows the generator driven by a steam turbine operating at 110 lb. steam pressure.* The bank of condensers shown at the right serves to correct the power-factor of the furnace circuit. In place of the steam turbine a synchronous motor can be used to drive the generator and to correct the power-factor of the primary power supply lines.

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*This turbine-generator was built by the General Electric Company.

The furnace illustrated has been used for melting nickel-silver and copper, and the stirring effect is as pronounced as in the smaller furnaces operated with oscillatory current. Copper to the amount of 600 lb. can be melted in a little over an hour with a power input of about 100 kw.

Fig. 4 shows the furnace containing molten copper being poured into a series of iron molds. The power can be applied during pouring, if necessary, to keep the contents at the proper pouring temperature. Fig. 5 shows the crucible poured clean except for the charcoal which is used to prevent oxidation of the copper during melting.

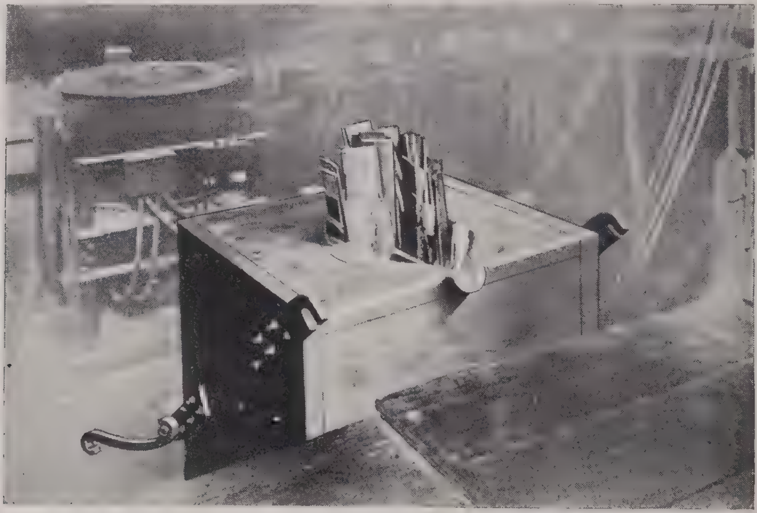

Fig. 2. A 600-lb. Furnace for Melting Copper and Nickel-silver by High-frequency Induction. The furnace after being completely emptied melts a new charge of 600 lb. of copper strips in one hour and nine minutes

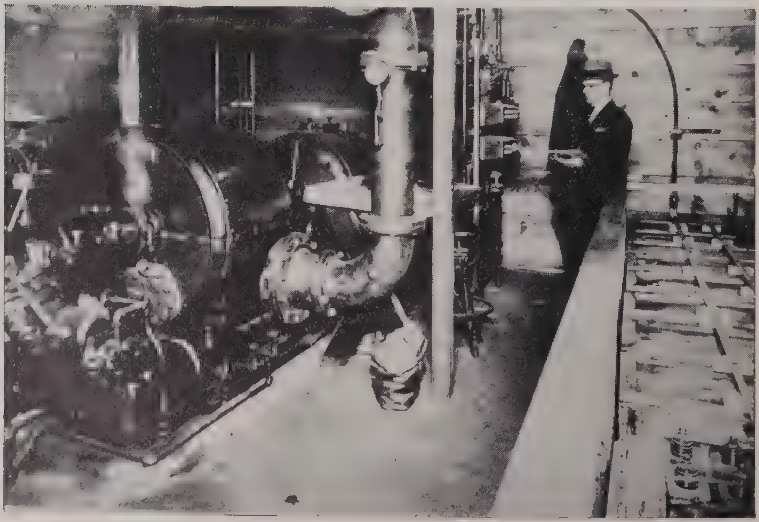

Fig. 3. Turbine-generator Delivering 100 kw. or More of High-frequency Power, and Condensers for Power-factor Correction for the Furnace Illustrated in Figs. 2, 4, and 5

The data in Table I are interesting as comparisons of the efficiency of the furnace in melting different materials and different forms of materials. In the first four cases the material was charged in the form of scrap pressed into "cabbages" and some loose scrap. The fifth melt consisted only of copper strips as illustrated in Fig. 2. The sixth melt was of a solid lump of nickel-silver which had been allowed to freeze in the crucible overnight. It will be noted that the efficiency in this last case was somewhat better than when cabbaged nickel-silver was melted as recorded in the first line of the tabulation. It is of high practical value that a molten mass may solidify in the crucible and be re-melted without cracking or injuring the crucible.

Another very interesting high-frequency furnace installation was made recently for melting nickel-iron and silicon-iron alloys in 225-lb. lots. These furnaces operate from a 5000-cycle generator that is driven by a direct-current motor. The generator is rated at 100 kw. and practically the full power is

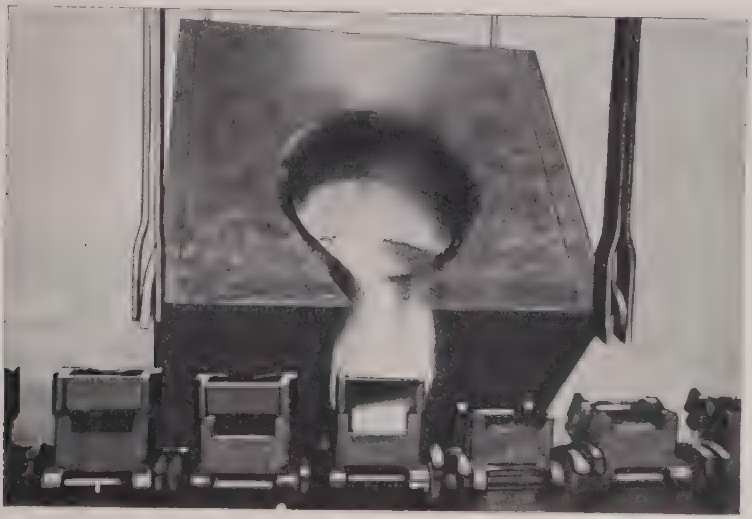

Fig. 4. A 600-lb. Charge of Copper Being Poured Into Iron Molds

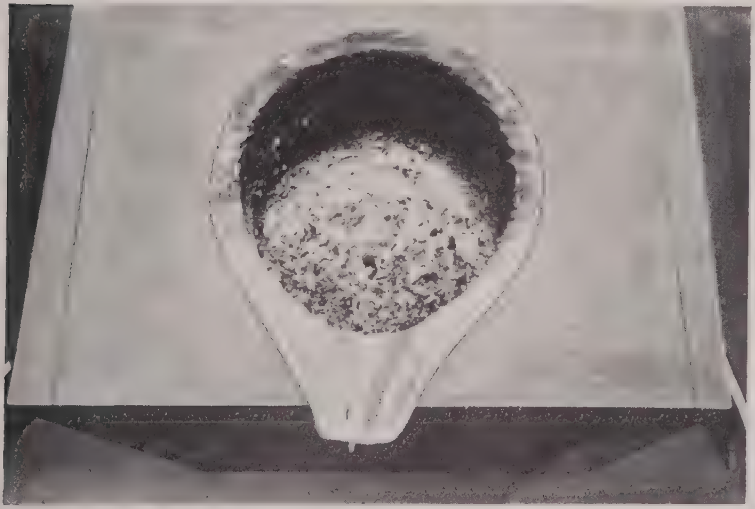

Fig. 5. Looking Down Into Crucible of 600-lb. High-frequency Induction Furnace, Shortly After Pouring

TABLE I

DATA OF MELTING DIFFERENT MATERIALS AND DIFFERENT FORMS OF MATERIAL

Crucible	Metal	Pounds	Kilowatt Rate	TIME OF MELTING Hr.	TIME OF MELTING Min.	Total Kw-hr. Consumed	Lb. Per Kw-hr.	Remarks
Cold	Nickel-silver	636	90.1	1	49	163.8	3.98	
Hot	Nickel-silver	636	92.8	1	18.6	121.8	5.23	
Cold	Common Brass	636	99	1	4	105.5	6.02	
Hot	Common Brass	636	99.5	–	43	71.3	8.9	
Hot	Copper	636	100	1	9	115.0	5.53	
Cold	Nickel-silver	600	84.9	2	22	115.70	5.19	Metal in solid lump at start.

(Data on last line taken by E. F. Northrup)

delivered to the furnace circuit. A melt takes less than an hour. The necessity for keeping the carbon content of the alloys to the astonishingly low figure of 0.006 per cent or less makes it necessary to use a non-carbonaceous crucible. Zircon crucibles are used and last only one heat but the cost of melting is nevertheless considered low. In some cases the melting is done in a vacuum; in others it is done in hydrogen. The furnace construction lends itself admirably to either. A section of an early design of the furnaces used in this installation is shown in Fig. 6. An etched section of an ingot of nickel-iron alloy weighing 225 lb. is shown in Fig. 7. Not the least interesting feature of the production is the fact that the ingots are not cropped. It will be observed from Fig. 7 that the ingot has a flat top. While there are a few shrinkage holes near the top they are found to weld on forging and so the entire ingot is rolled.

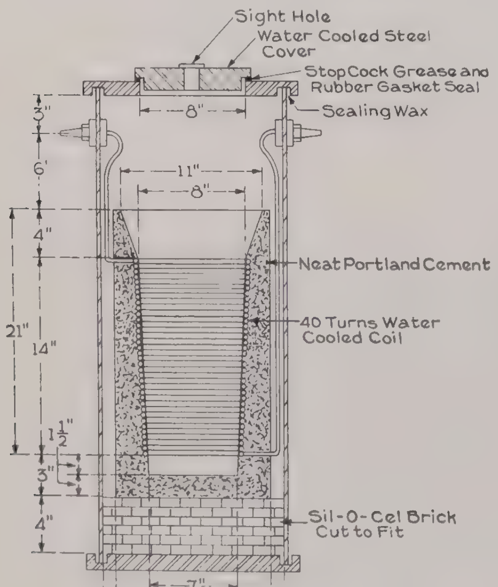

Fig. 6. Sectional Drawing of High-frequency Non-pouring Furnace Used for Melting Electrolytic Iron and Nickel

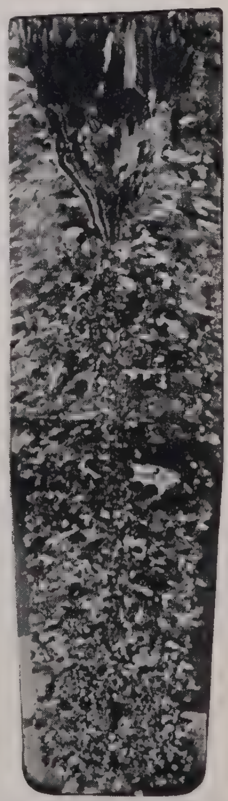

Fig. 7. Etched Section of a 225-lb. Ingot of Nickel-iron Alloy Produced in a 100-kw. High frequency Induction Furnace

All the high-frequency furnaces described in this article were built after designs made by Dr. E. F. Northrup, of the Ajax Electrothermic Corporation, Trenton, N. J.

Exciter Field Rheostats

By J. F. Formanek

Direct-current Engineering Department, General Electric Company

There is more to the design of a satisfactory exciter field rheostat than one would suppose off-hand. It is not the simple problem of determining the total resistance to be included and then dividing this into a number of equal resistance steps, operating on any one of which the rheostat will have a safe current-carrying capacity. The saturation curve of the exciter enters the problem and makes necessary the division of the total resistance into non-uniform steps that in effect tend to neutralize the departures of that curve from a straight line starting at the origin. How this matter is taken into account is explained in the following article.—Editor.

To be able to adjust the excitation of an alternator accurately and conveniently is an essential of good service performance and requires that the exciter voltage be under excellent control. This voltage when once adjusted should not only remain constant but for different operating conditions the attendant should be able to vary it over its range in increments small enough to give close regulation of the alternator voltage. The field rheostat by which this adjustment is made should therefore receive careful consideration by the designing engineer. The field rheostat should thus be so designed that each button when "turned in" or "turned out" will produce the same decrease or increase of exciter voltage, regardless of the voltage at which the machine is operating. This does not mean that the amount of resistance between rheostat buttons should be uniform throughout the whole range. On the contrary, due to the peculiar relation between the exciter field current and exciter voltage as shown by the well-known saturation curve, the resistance between buttons should be different. However, the value of resistance between buttons in any part of the rheostat can readily be calculated from the saturation curve of the exciter.

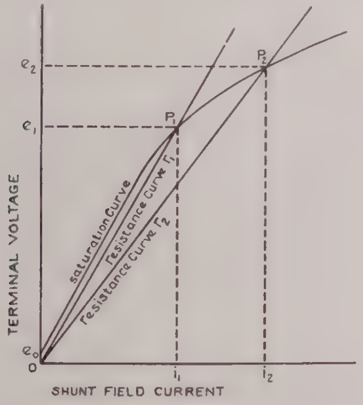

Fig. 1. Typical Saturation Curve of an Exciter

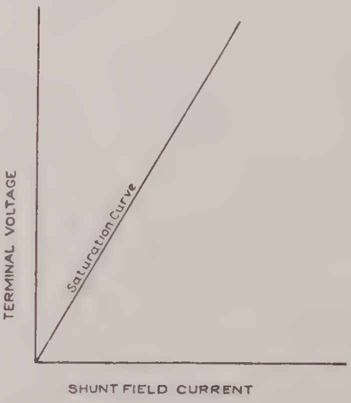

Fig. 2. Hypothetical Saturation Curve of an Exciter in Which the Effect of Residual Voltage and Magnetic Saturation is Neglected

In Fig. 1 is shown a typical saturation curve giving the relation between the terminal voltage and the current in the shunt field circuit. This curve also shows the relation between current in the shunt field circuit and voltage across it, since the shunt field is connected across the terminals of the exciter. By applying Ohm's Law to any point on the saturation curve, the resistance in the shunt field circuit for the particular value of terminal voltage chosen is readily obtained. For example, for the point P_1 the resistance in the field circuit is found by dividing the voltage e_1 by the corresponding current i_1. A straight line drawn through P_1 and the origin gives the relation in accordance with Ohm's Law between the terminal voltage and field current for the particular value of field resistance r_1. Other resistance curves for other points on the saturation curve can likewise be drawn. Thus, for each point on the saturation curve there is a corresponding resistance curve intersecting the saturation curve at that point, and indicating by its slope the amount of resistance in the shunt field circuit required for that exciter voltage.

The development of the characteristic curve giving the amount of resistance in the shunt field circuit at any terminal voltage is very interesting. Assume first that the saturation curve is a straight line passing through the origin as shown in Fig. 2. Then since for any voltage on this curve the ratio of the voltage to the corresponding current is constant, the resistance curves for any voltage have the same slope and thus coincide with the saturation curve. In other words, the amount of resistance in the field circuit for any voltage would be constant, and a curve showing the relation between resistance of the field circuit and terminal voltage would be a vertical straight line as shown in Fig. 3.

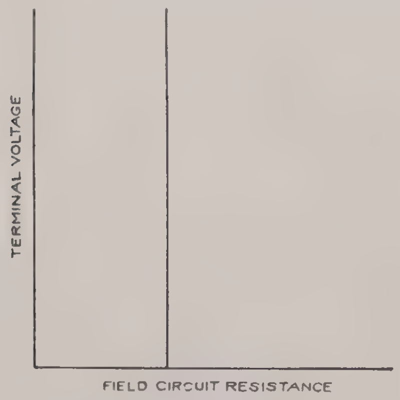

Fig. 3. Shunt Field Characteristic for Hypothetical Saturation Curve of Fig. 2

However, the actual saturation curve does not pass through the origin and only the air gap portion is a straight line. Due to residual magnetism it begins at some voltage e_0 and due to saturation it bends to the right at the top as shown in Fig. 1. The effect of the former is to bend the resistance curve to the right at the bottom, and of the latter to bend the resistance curve to the left at the top as shown in Fig. 4.

The bottom portion of this resistance curve goes to infinite resistance at residual voltage e_0, since when the field circuit is opened the terminal voltage of the exciter is not zero but that due to residual magnetism. The top portion of the resistance curve ends at some voltage e_3, which is the voltage of the exciter with the field rheostat "all out." Therefore the resistance r_f corresponding to this point is that in the field windings themselves, and all resistance greater than this value is in the rheostat. Thus a curve showing the relation between resistance in the rheostat and terminal voltage can be drawn by subtracting r_f from points on the resistance curve in Fig. 4. Such a curve is shown in Fig. 5.

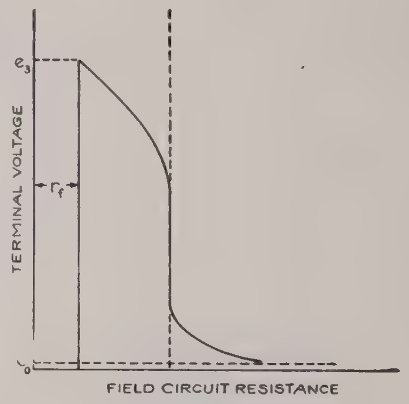

Fig. 4. Shunt Field Characteristic for the Typical Saturation Curve of Fig. 1

The horizontal scale in Fig. 5, which is terminal voltage, may be replaced by another scale, namely, "rheostat buttons," on the assumption of equal voltage increments per button. The total resistance in the rheostat up to any button may therefore be read directly from the curve, and the amount of resistance between buttons obtained by taking the difference between the resistance values for adjacent buttons. From this curve therefore a curve showing the relation between buttons, and resistance between buttons, may be drawn as shown in Fig. 6. This curve gives an idea of the proper resistance distribution in the rheostat for a typical saturation

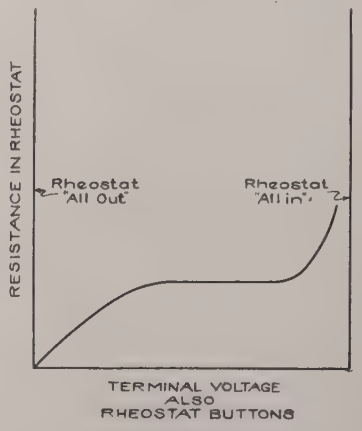

Fig. 5. Rheostat Resistance Curve

curve, under the assumption of equal voltage increments per button.

It is interesting to observe from the curve in Fig. 6 that near the middle of the rheostat there is a range where the resistance between buttons is relatively very small, and the total resistance in this range is only a small portion of the total rheostat resistance. This range corresponds to the straight portion of the saturation curve just below the bend, where the exciter is very sensitive to rheostat adjustment, and yet where many exciters normally operate. It is therefore important that this range be correctly located in the rheostat.

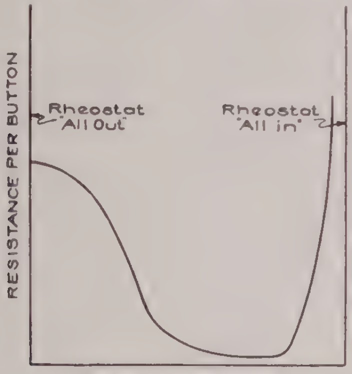

Fig. 6. Curve Showing the Characteristic Distribution of Resistance in an Exciter Field Rheostat

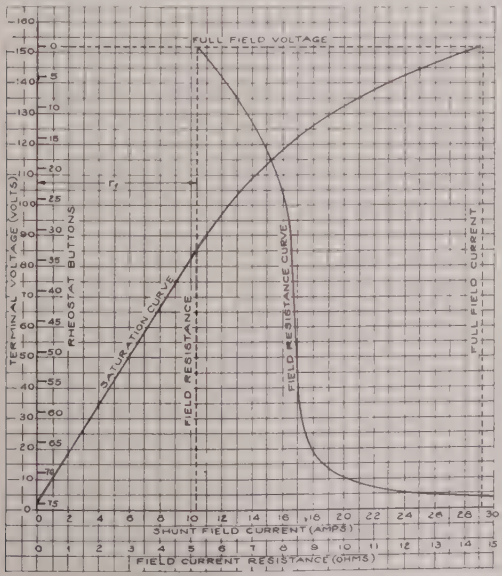

Fig. 7. Saturation and Field Resistance Curves of a 125-volt Exciter

It is impracticable to make the resistance between all buttons different, as shown in Fig. 6. Rheostats are made up of resistance units and if a number of these can be made alike the construction of the rheostat will be greatly simplified. To accomplish this the rheostat buttons are divided into groups, the resistance units of each group being alike, and the groups being arranged so as to approximate the resistance distribution of Fig. 6. The following example gives the practical method of design and selection of the resistance units.

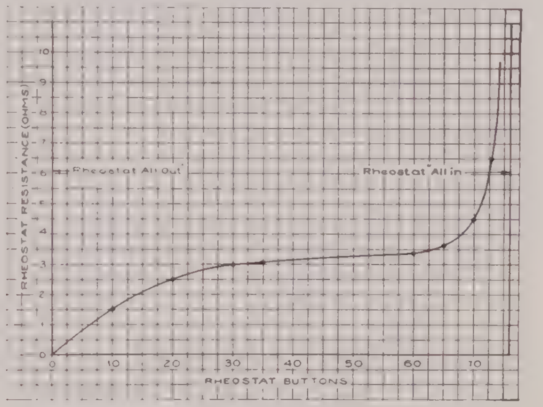

Fig. 8. Calculated Rheostat Resistance Curve for the 125-volt Exciter of Fig. 7

In Fig. 7 is given the saturation curve of a 125-volt exciter. In the same illustration is also given the field resistance curve which was obtained by dividing values of terminal voltage by the corresponding shunt field current as read from the saturation curve. The amount of resistance in the field windings

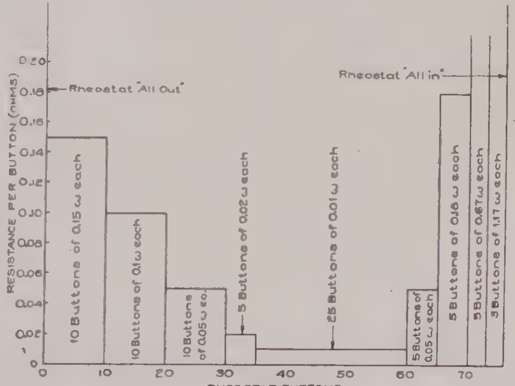

Fig. 9. Diagram Showing the Actual Distribution of Resistance in the Rheostat for the 125-volt Exciter of Fig. 7

r_f, as given by the full field voltage divided by the full field current, is 5.2 ohms.

Assume that a voltage change of about 2 volts per button is desired so that 76 buttons will be required for the 152 volts exciter range. The vertical scale in Fig. 7 can therefore be replaced by another scale of rheostat buttons. The origin of this scale will be at 152 volts where the rheostat is "all out."

The rheostat resistance curve of Fig. 8 is next obtained from the resistance curve of Fig. 7 by subtracting the constant value of field resistance, 5.2 ohms, from the values of field circuit resistance read from the curve. This curve thus gives the total amount of resistance "turned in" the rheostat up to any button. By subtracting the rheostat resistance for any one button from the rheostat resistance for the previous button, the resistance between buttons is obtained. Such a procedure would involve many calculations and take considerable time. A more satisfactory method is to divide the rheostat resistance curve of Fig. 8 into a number of sections (as indicated by the dots) so that straight lines drawn from one dot to the next will give a broken curve which nearly coincides with the original curve. Each of these sections then represents a group of rheostat buttons in which the resistance between buttons is the same. This resistance in each group is readily obtained as follows. In Fig. 8, the second section, from 10 to 20 rheostat buttons, covers 10 buttons. The resistance change is from 1.5 to 2.5 ohms, or 1.0 ohm. This value of resistance divided by 10 buttons gives 0.1 ohm per button. In Fig. 9 is given the rheostat resistance distribution curve obtained in this manner. This curve corresponds to the theoretical curve shown in Fig. 6. It will be observed that the rheostat is made up of only nine different resistance units.

The total resistance in the group of 25 buttons near the middle of the rheostat is only about 3 per cent of the total resistance in the field winding and rheostat up to this group. The slight inaccuracies introduced by variation between calculation and construction and changes of resistance with temperature, may be great enough to prevent reaching this group at the proper voltage. Some method must therefore be used to insure proper location of this group. One method is to provide at the beginning of the rheostat a few taps in the rheostat proper and a few external resistance units of the proper value so that the resistance up to the small buttons may be varied. The adjustments may be permanently made when the exciter is first installed.

The distribution of resistance in the rheostat is thus dependent upon the shape of the saturation curve of the exciter and is such as to give a central range in which the resistance between buttons is very small. This range corresponds to the straight portion of the saturation curve below the knee. By a proper distribution of resistance in the rheostat and a careful location of the range of small resistance units, a variation of the exciter voltage in equal increments can be obtained.

* * *

Study of Crystal Structure and Its Applications

PART III

THE LAUE METHOD OF CRYSTAL ANALYSIS

By Wheeler P. Davey

Research Laboratory, General Electric Company

In Part I of this series of articles it was stated that x-rays are used as a "micrometer" for measuring the inter-atomic distances in crystals. The theory of the "micrometer" was introduced and explained. In Part II the author outlined the different types of crystal structure so as to present more clearly the details of the micrometering process. In Part III we come to the actual application of x-ray diffraction technique to crystal analysis. It is interesting to note that there are several independent methods of using the distances between atomic planes as found by x-rays in the solution of crystal structure. These methods give results that are substantially in agreement. Such agreement is of great importance in any scientific investigation, for it provides a check on the validity of the hypothesis. In this case it is of especial value because the work being done on crystal structure is destined to be of enormous worth both to physics and engineering. These various x-ray methods will be taken up in the order of their discovery. In the present article Dr. Davey outlines the method discovered by Professor M. Laue, of the University of Munich, Germany.—Editor.

X-ray Spectra and Their Application to Crystal Analysis

The beam of x-rays given off by an x-ray tube contains waves of every possible wavelength from the longest x-ray waves known down to a limit which is determined only by the voltage across the x-ray tube. This limiting wavelength λ_0 may be calculated at once from the voltage across the tube by the "quantum equation,"

$$\lambda_0 = \frac{hc}{E_1 e} \qquad (33)$$

where h is the proportionality constant (Planck's constant) $= 6.55 \times 10^{-27}$ erg/sec.

c is the velocity of light $= 3 \times 10^{10}$ cm/sec.

E_1 is the potential difference across the x-ray tube in absolute electromagnetic units $=$ volts $\times 10^8$.

e is the charge on the electron in absolute electromagnetic units $= 1.591 \times 10^{-20}$ a.e.m.u.

Since e, h, and c are all constants, equation (33) may be written

$$\lambda_0 = 1.234 \times 10^{-4}\ E_2^{-1} \qquad (34)$$

where E_2 is the potential difference across the x-ray tube in volts. By analogy with visible light, a beam of x-rays which contains all possible wavelengths within the limits given above is usually called a beam of "white" x-rays.

For every element there are groups of wavelengths which are characteristic of that element. These groups are called the K, L, M and N series. The target of an x-ray tube emits the wavelengths of a given one of its characteristic series with relatively large intensities when the voltage across the tube exceeds the quantum limit for the shortest wavelength of that series. The effect is as though the characteristic rays were superimposed on the "white" x-rays. X-ray spectra are illustrated in Figs. 11 and 12, taken from articles by A. W. Hull in "X-ray Studies of the Research Laboratory," General Electric Company. The voltages calculated from equation (34) which are necessary to produce characteristic rays from the various elements are given in Table IV.

These peculiarities of x-ray spectra have all been utilized by one or another of the various methods of x-ray crystal analysis. The Laue method uses the "white" rays. The Bragg and "powder" methods use one of the characteristic wavelengths. The Clark and Duane method uses the limiting wavelength given by equation (34). Each of these methods has its own advantages and disadvantages for various kinds of work. It will therefore be worth our while to take up each in turn.

The Laue Method

If a crystal is placed in the path of "white" x-rays it will, in general, diffract some of the x-rays, for no matter what plane of atoms in the crystal may be inclined to the beam, there will be some wavelength present which will require just that grazing angle of incidence for diffraction from that family of planes. In other words, for any values of d and θ in equation (1) there will be found in the beam some value of λ such that diffraction can occur, provided only that the voltage across the x-ray tube is high enough to produce that wavelength. Since the atoms of a crystal have an orderly arrangement in all three dimensions in space, it follows that diffraction of x-rays will occur from many families of atomic planes at once, each family picking out the wavelength which it can diffract at the angle at which it finds itself. This is illustrated diagrammatically in Fig. 13. The sort of diffraction pattern obtained is illustrated in Fig. 14, first published in the original work of Friedrich, Knipping and Laue.(28)

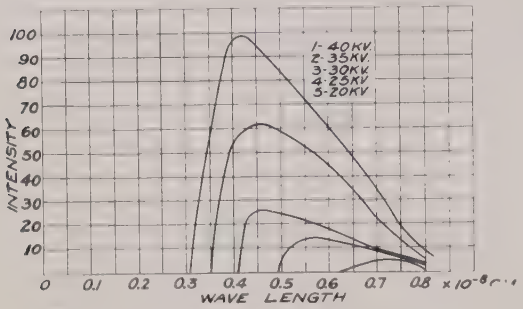

Fig. 11. Spectrum of "White" X-rays. (Hull)

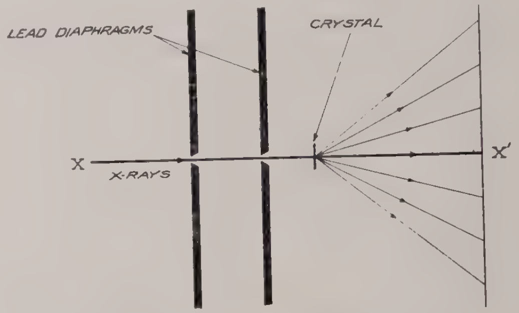

Fig. 12. Characteristic X-ray Spectrum of W Superimposed on "White" Spectrum. (Hull)

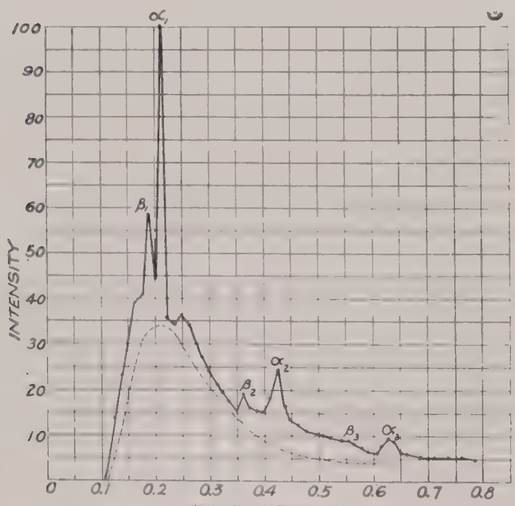

Fig. 13. Diffraction of "White" X-rays by a Single Stationary Crystal

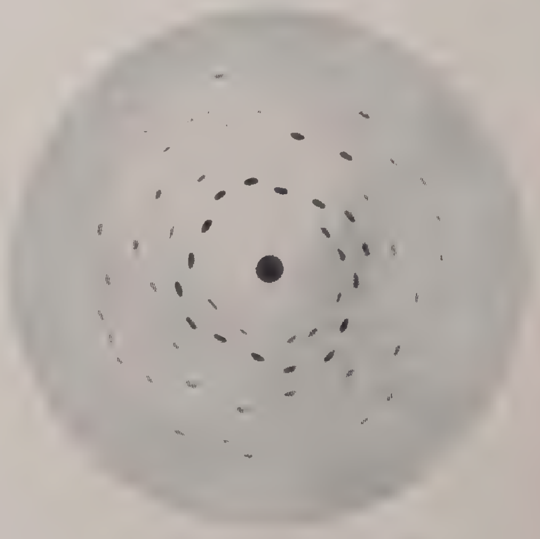

Fig. 14. Laue Diffraction Pattern of Zinc Blend. The rays pass through the crystal parallel to one of the cubic axes

When the primary beam passes along an axis of symmetry of the crystal, the Laue pattern consists of a series of "spots" whose loci are ellipses which pass through the "central image" made by the primary beam, and which are symmetrically placed around it. This is shown in Fig. 15. W. L. Bragg's explanation of the elliptical shape of these loci is as follows.(29) Let the primary beam approach the crystal in the direction of one of its axes, for instance, the Z-axis in Fig. 16. It will pass through the crystal at O and strike the photographic plate at P, producing the "central image." If the line OQ is the direction of some row of atoms in the crystal, i.e., if it is a "zone axis," then OQ is necessarily the intersection of several atomic planes. If one of these happens to lie in the YOQ plane, the diffracted beam will make a "spot" on the photographic plate at R. Other atomic planes passing through OQ will cause diffracted beams whose locus is the surface of a cone whose altitude is along OQ and whose generators lie along OR and OP. The intersection of this cone with the photographic plate is an ellipse.

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(28) Friedrich, Knipping and Laue, Sitzbr. d. bayer Akad. d Wiss. *Math-phys.*, 303, 363 (1912); *Ann. d. Phys.* 41, 971 (1913).

(29) W. L. Bragg, *Proc. Roy. S* , A 89, 246 (1913).

In the Laue method a crystal is used such that its faces may be identified by ordinary crystallographic methods. This implies that the type of crystal structure must be assumed to be that found by the ordinary crystallographic measurements of the angles between faces, for if the faces of the specimen crystal are wrongly identified, the procedure outlined below becomes valueless. The crystal is mounted so that one of its faces is perpendicular, or nearly perpendicular, to the direction of the incident primary beam. This makes it possible to calculate at once the angle of grazing incidence between the incident beam and any atomic plane which may be assumed to exist in the crystal. In this way the position of each spot on the photograph may be referred directly to the family of planes which give rise to it.(29)

TABLE IV

Potential difference in kilovolts across the x-ray tube required to excite the characteristic x-ray spectral lines.—*From "Spectroskopie der Roentgenstrahlen," by M. Siegbahn (Julius Springer, 1924).*

	K	L	M	N		K	L	M	N
92 U	115	21,7	5,54	1,44	47 Ag	25,5	3,79	0,72	0,10
90 Th	109	20,5	5,17	1,33	46 Pd	24,4	3,64	0,67	0,08
83 Bi	90,1	16,4	4,01	0,96	45 Rh	23,2	3,43	0,62	0,07
82 Pb	87,6	15,8	3,85	0,89	44 Ru	22,1	3,24	0,59	0,06
81 Tl	85,2	15,3	3,71	0,86	42 Mo	20,0	2,87	0,51	0,06
80 Hg	82,9	14,8	3,57	0,82	41 Nb	19,0	2,68	0,48	0,05
79 Au	80,5	14,4	3,43	0,79	40 Zr	18.0	2,51	0,43	0,05
78 Pt	78,1	13,9	3,30	0,71	39 Yt	17,0	2,36		
77 Ir	76,0	13.4	3,17	0,67	38 Sr	16,1	2,19		
76 Os	73,8	13,0	3,05	0,64	37 Rb	15,2	2,05		
74 W	69,3	12,1	2,81	0,59	35 Br	13,5	1,77		
73 Ta	67,4	11,7	2,71	0,57	34 Se	12,7	1,64		
72 Hf	65,4	11,3	2,60	0,54	33 As	11,9	1,52		
71 Lu	63,4	10,9	2,50	0,51	32 Ge	11,1	1,41		
70 Yb	61,4	10,5	2,41	0,50	31 Ga	10,4	1,31		
69 Tm	59,5	10,1	2,31	0,47	30 Zn	9,65	1,20		
68 Er	57,5	9,73	2,22	0,45	29 Cu	8,86			
67 Ho	55,8	9,38	2,13	0,43	28 Ni	8,29			
66 Dy	53,8	9,03	2,04	0,42	27 Co	7,71			
65 Tb	52,0	8,70	1,96	0,40	26 Fe	7,10			
64 Gd	50,3	8,37	1,88	0,38	25 Mn	6,54			
63 Eu	48,6	8,04	1,80	0,36	24 Cr	5,98			
62 Sm	46,8	7,73	1,72	0,35	23 Va	5,45			
60 Nd	43,6	7,12	1,58	0,32	22 Ti	4,95			
59 Pr	41,9	6,83	1,51	0,30	21 Sc	4,49			
58 Ce	40,3	6,54	1,43	0,29	20 Ca	4,03			
57 La	38,7	6,26	1,36	0,27	19 K	3,59			
56 Ba	37,4	5,99	1,29	0,25	17 Cl	2,82			
55 Cs	35,9	5,71	1,21	0,23	16 S	2,46			
53 I	33,2	5,18	1,08	0,19	15 P	2,14			
52 Te	31,8	4,93	1,01	0,17	14 Si	1,83			
51 Sb	30,4	4,69	0,94	0,15	13 Al	1,55			
50 Sn	29,1	4,49	0,88	0,13	12 Mg	1,30			
49 In	27,9	4,28	0,83	0,12	11 Na	1,07			
48 Cd	26,7	4,07	0,77	0,11					

The Gnomic Projection

The labor of this computation may be greatly lessened by the graphical method of F. E. Wright and R. W. G. Wyckoff.(30) This method employs the gnomic projection (31, (32) (33) (34) illustrated in Fig. 17. The primary beam of x-rays passes through the crystal at *O* and strikes the photographic plate at *P*. On its way through the crystal at *O* it will strike some atomic plane. Let us assume that this plane is perpendicular to the plane of the paper (Fig. 17) and that it passes through the zone axis *OQ*. A perpendicular drawn to this plane at *O* will strike the plane of projection at *S*. Then *S* is the gnomic projection of this plane of the crystal. The distance from the "spot" on the photographic film at R to the central image at P is $PR=PO \tan 2\theta$. The distance from the central image to S is $P'S=P'O \tan (90°-\theta)$. The gnomic projection therefore comes at

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(30) R. W. G. Wyckoff, *Am. Jour. Sci.*, *50*, 317 (1920).

(31) V. Goldschmidt, "Ueber Projektion und Krystallberechnung," (1887).

(32) H. E. Boeke, "Die Gnomische Projektion" (1913).

(33) R. Rinne, Ber Verh, K. Sachs, Ges., *67*, 303 (1915).

(34) C. Palache, *Am. Mineralogist*, *5*, 67 (1920).

$$P'S=PR\,\frac{P'O \cot \theta}{PO \tan 2\theta}$$

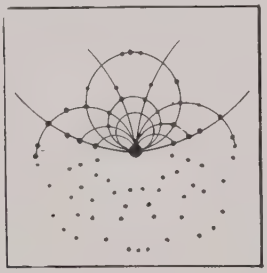

Fig. 15. Elliptical Loci of Spots of Laue Pattern

In practice PO is from 3 to 5 cm., and $P'O$ is usually 5 cm. Convenient tables for gnomic projection have been published by Wyckoff.(30) His projected Laue patterns of rutile (Figs. 18 and 19) and of rhodochrosite (Fig. 20) illustrate how the names of the various atomic planes are related to the corresponding points of the projection.

Let us assume that the crystal belongs to the cubic system and that the x-rays strike it in the direction of the Z-axis. The positions of the X- and Y-axes are known from

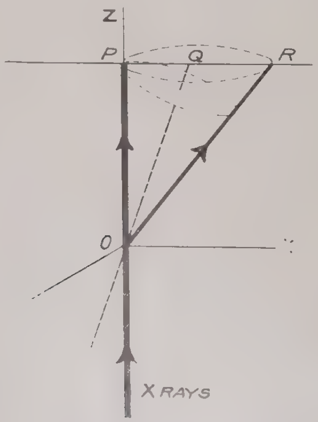

Fig. 16. Bragg's Explanation of Elliptical Loci

the external symmetry of the crystal. Fig. 21 gives the gnomic projections of typical planes which lie perpendicular to the Y-axis.(35)

It is evident that S_1, which is the gnomic projection of the plane Q_1OY, is exactly as far from the central image P' as is the crystal O, and that $P'S_1=S_1S_2=S_2S_3$. This means that if the plane of projection is $P'O$ cm. from the crystal, then the gnomic projections which fall in the direction of the X-axis are all $P'O$ cm. apart from each other. Similarly the gnomic projections which fall in the direction of the Y-axis are $P'O$ cm. apart. The gnomic projection of a cubic crystal is therefore based on a network of squares whose sides are equal to the distance from the crystal to the plane of projection. The indices of the planes whose projections fall at the intersections of this network may be read off directly in terms of the co-ordinates of their projections on the network, remembering that the "1" index (reciprocal of the intercept of the plane on the plane on the Z-axis) is necessarily unity. Indices of other planes may be determined by first expressing them as fractions and then changing them to their lowest possible integers. For instance, in Fig. 20, the projection of plane 1 2 . 2 is first found as ½ 1 . 1; the projection of plane 4 3 . 4 is first found as 1 ¾ . 1, etc.

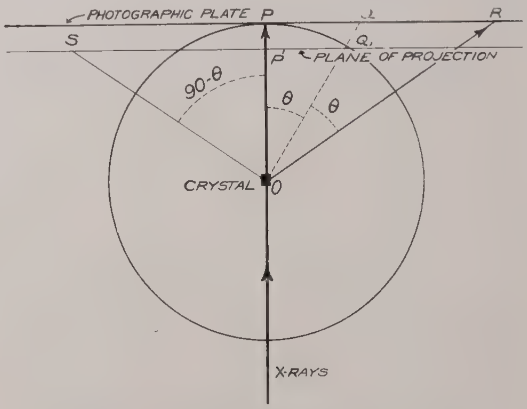

Fig. 17. Gnomic Projection of a Laue Spot

If the crystal is tetragonal, and the primary beam of x-rays is made to pass parallel to the Z-axis (i.e., parallel to the axis which has a different unit of length than the other two) then the gnomic pattern will be built up of a network of squares as in the case of a cubic crystal, but with this difference—the sides of the squares are no longer equal to the distance from the crystal to the plane of projection, but to this distance multiplied by the axial ratio, C, of the crystal. It has been already stated(36) that any body-centered tetragonal crystal may be regarded as a face-centered tetragonal crystal by dividing the axial ratio by $\sqrt{2}$. For this reason the network of Fig. 18 may be replaced by a square network placed at 45 deg. to the one shown in the drawing. Since the sides of the new squares are the diagonals of the old, the scale of the network is increased in the same ratio as the increase in the unit of measure along the Z-axis. If the primary beam of x-rays is made to pass parallel to the X- or Y-axis, then the gnomic network will be composed of rectangles. One side of the rectangles will be equal to the distance from the crystal to the plane of projection. The other side will be this distance multiplied by the axial ratio C. If the crystal is orthorhombic, the lengths of the sides of the rectangles in the network will have the same ratio to each other as the corresponding axial ratios in the crystal.

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(35) Corresponding points in Figs. 16, 17 and 21 are given corresponding symbols.

(36) See Part II, Dec. 1924, p. 799, paragraph on Triangular or Hexagonal Lattices.

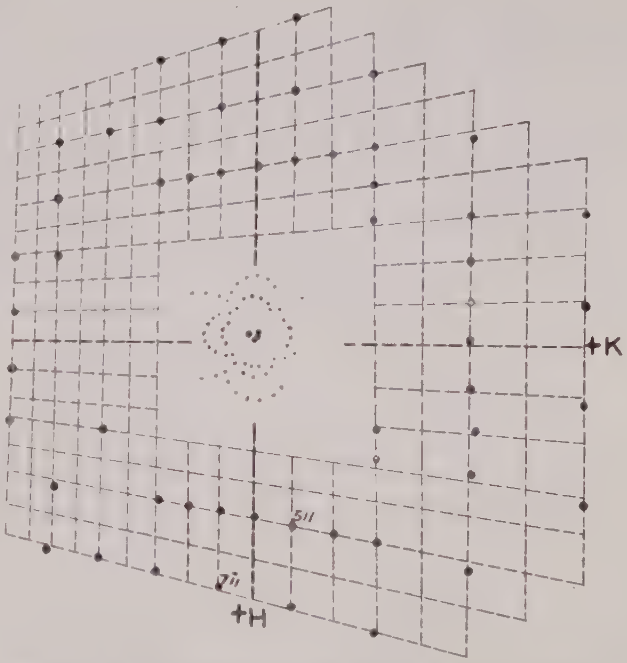

Fig. 19 Gnomic Projection of Laue Pattern of Rutile. Primary beam at an angle to the Z-axis. (Wyckoff)

If the crystal is a rhombohedron or has a triangular close-packed lattice, and if the primary beam of x-rays passes parallel to the Z-axis, then the gnomic network will consist of parallelograms whose sides make an angle of 120 deg. (See Fig. 20. This angle corresponds to the angle between the X- and Y-axes. The network therefore names the planes of the crystal in terms of the reciprocals of the intercepts on the hexagonal system of axes. In the case of the rhombohedral lattice the hexagonal indices may be transformed, if desired, into indices referred to the edges of the rhombohedron by the equations

$$h_1 = 2\,h + k + l$$
$$k_1 = -h + k + l$$
$$l_1 = -h - 2\,k + l$$

where h, k, l are the indices in terms of the hexagonal axes and h_1, k_1, l_1 are the indices in terms of the edges of the rhombohedron. In this connection see Table III.

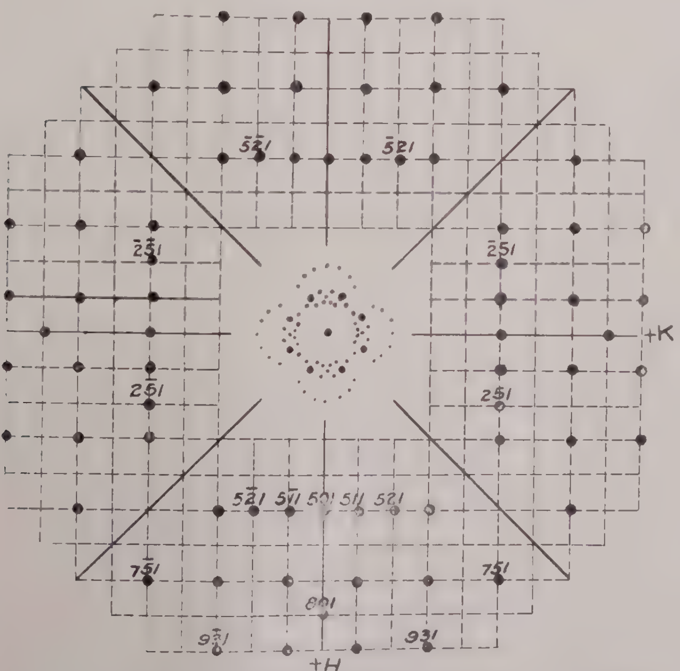

Fig. 18. Gnomic Projection of Laue Pattern of Rutile (TiO_2). Primary beam parallel to Z-axis. (Wyckoff.) TiO_2 is face-centered tetragonal with an axial ratio $C = 0.455$

If the crystal is monoclinic and the primary beam is parallel to the Z-axis, the network is composed of parallelograms whose angle is determined by the angle between the X- and Y-axes. If the x-ray beam is parallel to the X- or Y-axes the network is rectangular but is displaced so that the origin of co-ordinates is not at the center of the projection. If the crystal is triclinic the network is composed of parallelograms whose origin of co-ordinates is not at the center of the projection.

If the primary beam of x-rays is not quite parallel to one of the axes of the crystal, the gnomic projection is slightly distorted as in Fig. 19, but for angles less than 10 deg. the distortion does not usually prevent the easy identification of atomic planes. For a more detailed discussion of the gnomic projection as applied to the study of Laue patterns, the reader is referred to "The Study of Crystals" by R. W. G. Wyckoff, American Chemical Society Monograph Series (1924).

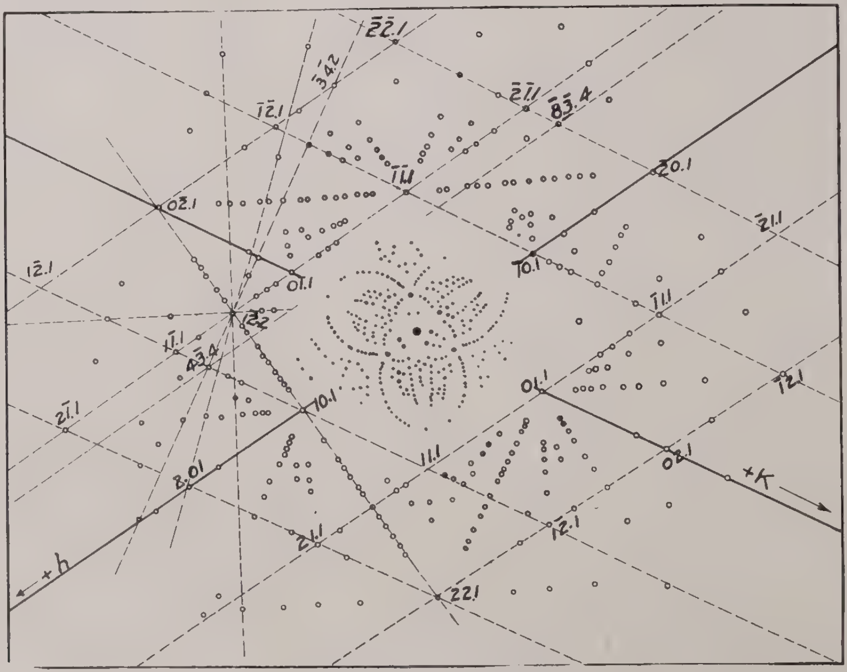

Fig. 20. Gnomic Projection of Laue Pattern of Rhodochrosite. Primary beam approximately normal to the basal (1 1 1) plane

Interpretation of the Laue Pattern

Once the "spors" of the Laue pattern have been identified in terms of the atomic planes which produced them, there remains the problem of using these spots to determine the structure of the crystal. The simplest case is that of a crystal of an element, for since all its atoms are alike, their diffracting powers under similar conditions may be assumed to be all alike. Let us assume for purpose of illustration that a given element has a "simple cubic" structure, although actually no such element is known. Then from equation (18)* we can calculate the relative distances between its various families of planes in terms of the side of the unit cube, and every such plane should be represented by a "spot" in its proper place in the gnomic projection, provided only that a suitable wavelength from the primary beam is available for producing the "spot" on the photographic film. If, however, the crystal is body-centered cubic, certain planes are only half as far apart as they would be if the crystal were a simple cubic. An instance of this is the 1 1 1 plane. If the crystal is body-centered cubic no gnomic projection of "spots" will be found at $h=1$, $k=1$; $h=\bar{1}$, $k=1$; $h=1$, $k=\bar{1}$; $h=\bar{1}$, $k=\bar{1}$. The same will apply to every plane for which the numerator of equation (18) is 1/2. Similarly, the Laue pattern of a face-centered cube (or some other division of the cubic system) is characterized by the absence of "spots" of those planes for which the numerator of equation (18) differs from unity. The same sort of procedure may be applied in the case of other crystal systems.

It is of course evident that for such comparatively simple structures the various families of planes which differ only in the sign of their indices will act similarly. That is, if the 1 1 1 position in the gnomic network is vacant, then the $\bar{1}\,1\,1$, $1\,\bar{1}\,1$, and $1\,1\,\bar{1}$ positions are also vacant. Otherwise some other, and possibly more complicated, structure must be found which is consistent with the Laue pattern and its gnomic projection. This implies also that it must be consistent with the symmetry of the crystal as determined by ordinary crystallographic methods. By reason of its systematic listing of the various geometrical configurations possible for different symmetries, the "Theory of Space Groups"(37) is useful in this connection as a means of insuring that no possible interpretation of the crystal structure is overlooked which might be consistent with the Laue pattern. We shall, therefore, consider the way in which this theory may be used as an aid in the determination of the structure of a crystal. This procedure will, of course, apply to the crystals of either elements or compounds.

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* For convenience of reference, equations (1) to (16) will be found in Part I (Nov. 1924, p. 742), and equations (17) to (32) in Part II (Dec. 1924, p. 795).

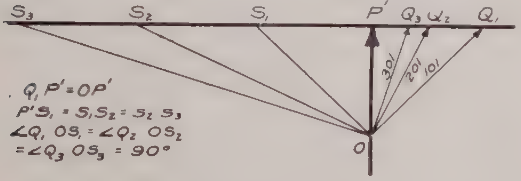

Fig. 21. Gnomic Projection in the XZ or YZ Plane for a Cubic Crystal

In general, when using the theory of space groups, the method of determining the structure of a crystal from the gnomic projection of its Laue pattern consists of three steps which are briefly as follows:—

(1) The selection of the type of symmetry required by the exterior of the crystal. This limits the possible marshalling of atoms to those "space groups" which are consistent with this symmetry.

(2) The determination of the dimensions of the unit-crystal and from these the determination of the number of atoms in the unit-crystal. This serves to further limit the number of possible "space groups" found in (1).

(3) The selection from the structures found in (2) of the one which is most consistent with the Laue pattern. This often involves certain assumptions which may not be rigorously true, but which are on the whole consistent with existing data.

For most crystals, the first step may be taken with the aid of any good crystallography. Groth's *Chemische Krystallographie* (Leipsic, 1906) is probably the most complete to date. The crystallographic system to which the crystal belongs determines the general shape of the unit-crystal. For instance, if the crystal belongs to the cubic system the unit-crystal is necessarily a cube; if it belongs to the hexagonal system the unit-crystal is a hexagonal prism, etc. In some cases a choice is possible between two or more unit-crystals for the same substance—for instance, a rhombohedral crystal may be regarded as having as its unit-crystal a triangular prismatic structure,(38) or it may be regarded as having a unit-crystal of rhombohedral shape. In the latter case a choice of one of two rhombohedra is possible.

The second step in the solution of the crystal structure requires data not obtainable from the Laue pattern. One of the faces of the crystal is rotated slowly in the path of a beam of x-ray consisting essentially of a single, known wavelength. The angles at which diffraction occurs are noted and from them not only can the order of diffraction n of equation (1) be determined, but also the interplanar distance d of equation (1) can at once be calculated. From this value of d the distance between any two adjacent planes of atoms in the crystal can be calculated by the methods previously given,(39) assuming the simplest possible lattice in the crystal system—i.e., simple cube, simple triangular prism, etc. The volume of this simple model of the unit crystal is then calculated, and its mass is determined (at least approximately) in terms of the published data for the density of the crystal. From the molecular weight of the substance of which the crystal is composed and the fact that one unit of atomic weight is equal to 1.649×10^{-24} grams, the number of molecules per unit crystal is at once found. From this and the chemical symbol of the substance of which the crystal is composed, it is possible to find at once the number of atoms of each kind in the unit-crystal. A check may be obtained upon the unit-crystal assumed above by calculating the value of $n\lambda$ from equation (1) for each spot in the Laue pattern, using in each case the value of d determined above for the planes which gave rise to the "spot" and the value of θ given by the Laue pattern. In no case must the value of $n\lambda$ calculated in this way be less than the minimum wavelength (λ_0 of equation [33]) present in the x-ray beam. The distribution in space of the atoms in the unit-crystal is, of course, limited to those "space groups" which are consistent with the data so far obtained. In other words, we have a limited number of possibilities for the co-ordinates of the various atoms of which the crystal is composed.

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(37) R. W. G. Wyckoff, "An Analytical Expression of the Results of the Theory of Space Groups," *Publication No. 318 Carnegie Institution of Washington* (1922).

The results of the Theory of Space Groups are given in convenient diagrammatic form by W. T. Astbury and K. Yardley, *Phil. Trans. Roy. Soc.*, A. *224*, 221 (1924).

See also:

L. Sohncke, "Entwickelung einer Theorie der Krystallstructur" (Leipsig, 1879).

A. Schoenflies, "Krystallsysteme and Krystallstructur" (Leipsig, 1891).

W. Barlow, *Zeit. f. Kryst. 23*, 1 (1894).

E. Federov, *Zeit f. Kryst. 24*, 209 (1895).

H. Hilton, "Mathematical Crystallography" (Oxford, 1903).

S. Kreutz, "Elemente der Theorie der Krystallstructur," (Leipsig, 1915).

P. Nigglie, "Geometrische Krystallographie des Discontinuums," (Leipsig, 1919).

R. W. G. Wyckoff, *Am. Jour. Sci. 1*, 124 (1921).

A. Schoenflies, "Theorie der Krystallstructur" (Berlin, 1923).

(38) See Part II, Dec., 1924, p. 799 ff.

(39) See Part II, Dec., 1924, pp. 796–800.

There now remains the third step in the solution by which, as far as is possible, the choice of co-ordinates for the atoms is further narrowed down by a consideration of the intensities of the various diffracted beams. These intensities are usually estimated roughly in terms of the blackness of the "spots" in the Laue pattern. Using the language of the wave-theory of radiation, the amplitude of the beam of x-rays diffracted from any given family of planes in the crystal will be the vector sum of the amplitude of the wavelets sent out from each of the planes in that family. This problem is then really the old problem of adding together wave motions which have the same wavelength, but which differ in both phase and amplitude.(40) It is well known that in such a problem the square of the resultant amplitude may be expressed in terms of the sum of the squares of two numbers which represent respectively the sum of the components, taken 90 deg. apart, of the amplitude of all the constituent wavelets, so that

$$R^2 \propto A^2 + B^2 \qquad (35)$$

To find the values of A and B we must know both the amplitude and the phase of every constituent wavelet. The amplitude of the wavelet diffracted from a given plane of atoms in the crystal depends upon many factors, but for any given order of diffraction from a single family of planes we are only concerned with one, namely the effect of the kind of atoms in each individual plane. We do not need to consider the effects of temperature, angle of diffraction, atomic population of the planes or "warping" of the plane surface, for these may be considered to be constant for the members of any given family of planes. It is assumed that the amplitude of a wavelet diffracted from any single plane is proportional to the atomic number, N, of the atoms which compose the plane. This assumption is consistent with our fundamental ideas on the diffraction of x-rays. It appears to have some experimental justification, for, as the Braggs have pointed out, the two fluorine atoms ($2N = 2 \times 9 = 18$) in CaF_2 seem to have about the same diffracting power as the calcium atom, for which N is 20. This assumption does not, in its ordinary form, include any effect of the distribution of the electrons in space, so it is not quite consistent with the experimental fact (41) that Na^+ ($N = 11 - 1$) and F^- ($N = 9 + 1$) differ slightly in diffracting power. It is, however, sufficiently accurate to enable one to distinguish between the various possible alternatives of crystal structure found in actual practice. It therefore remains only to express the phase difference between the wavelets diffracted from successive atomic planes in the same family in terms of the co-ordinates of the various atoms in the unit-crystal.

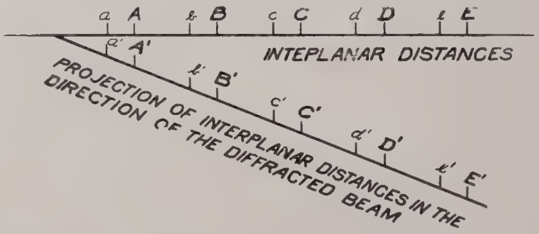
a A
b B
c C
d D
e E
a' A'
INTEPLANAR DISTANCES
b' B'
c' C'
d' D'
e' E'
PROJECTION OF INTERPLANAR DISTANCES IN THE DIRECTION OF THE DIFFRACTED BEAM

Fig. 22. Projection of Interplanar Distances in the Direction of the Diffraction Beam

Let the lines, a, A, b, B, etc., of Fig. 22 represent the members of some family of planes in a crystal. Let the lines a', A', b', B', etc., represent the projections of these planes in the direction of the diffracted beam. If the crystal had had the simplest structure for the crystallographic system to which it belongs (in the case of the cubic system this is "simple cubic"; in the case of the hexagonal system it is "simple triangular," etc.) the successive members of the family would have been at a, b, c, etc., and nowhere else. In such a case the distances $a'b'$, $b'c$, etc., would have to be such that a wavelet from a would meet the wavelet from b exactly in phase, otherwise there would have been no diffracted beam. The phase difference between these wavelets, expressed in circular measure in the usual way is therefore $2\pi n$ where n is the order of diffraction. The phase difference between the wavelets from a, b, c, etc., and A, B, C, etc., is

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(40) In this connection see A. Schuster, "The Theory of Optics," Chap. 1. (Edward Arnold, London, 1909, 1919). The same problem in another guise appears in alternating-current work.

(41) W. P. Davey, *Phys. Rev.* *21*, 143 (1923).

$$\psi = 2\pi n\ \frac{a'A'}{a'b'} = 2\pi n \frac{aA}{ab}$$

At this point let us limit ourselves temporarily to the cubic system. The distance ab is the interplanar distance in a simple cube. In terms of the side of the unit cube it is, by equation (18), $\sqrt{h^2+k^2+l^2}$. By equation (17) the distance from plane a to plane A is $aA = bB$, etc.,

$$= \frac{(hx_1+ky_1+lz_1-1)-(hx_2+ky_2+lz_2-1)}{\sqrt{h^2+k^2+l^2}}$$

where $x_1y_1z_1$ and $x_2y_2z_2$ are the co-ordinates of atoms in the two planes. Now if one of these planes is considered to pass through the origin of co-ordinates, $x_2=y_2=z_2=0$ and

$$aA = bB, \text{ etc.,} = \frac{hx_1+ky_1+lz_1}{\sqrt{h^2+k^2+l^2}}$$

then
$$\frac{aA}{ab} = \frac{\dfrac{hx_1+ky_1+lz_1}{\sqrt{h^2+k^2+l^2}}}{\dfrac{1}{\sqrt{h^2+{}^2k+l^2}}}$$

$$= hx_1+ky_1+lz_1$$

The phase difference between wavelets from a and A, b and B, etc., is therefore

$$\psi = 2\pi\ n\ (hx_1+ky_1+lz_1) \qquad (36)$$

If the crystal had belonged to any other than the cubic system the result would have been the same because the denominators of both portions of the complex fraction necessarily are identical and cancel out. Remembering our assumption as to the dependence of the amplitude of the wavelets upon the atomic number, we have for the two components of each wavelet in the A and B directions of equation (35)

$$N \cos 2\pi\ n\ (hx_1 + ky_1 + lz_1)$$

and
$$N \sin 2\pi\ n\ (hx_1 + ky_1 + lz_1)$$

For a given family of planes, A and B will each contain as many such terms as there are atomic planes in the unit-crystal which belong to that family. The intensity of the "spot" in the Laue pattern is therefore proportional to

$$[N_1 \cos 2\pi\, n\, (hx_1 + ky_1 + lz_1) + N_2 \cos 2\pi\, n\, (hx_2 + ky_2 + lz_2) + \ . \ . \ . \ .]^2$$
$$+ [N_1 \sin 2\pi\, n\, (hx_1 + ky_1 + lz_1) + N_2 \sin 2\pi\, n\, (hx_2 + ky_2 + lz_2) + \ . \ . \ . \ ]^2 \qquad (37)$$

The values of N_1, N_2, etc., are known from the chemical constitution of the crystal. The theory of space groups gives the co-ordinates $x_1\ y_1\ z_1$, $x_2\ y_2\ z_2$, etc., either directly or in terms of an undetermined distance from some known position in the unit-crystal. In one case the co-ordinates are substituted directly in (37) as a means of choosing between the alternative structures offered by the theory of space groups. In the other case, various numerical values are substituted systematically for the undetermined distance until one is found which gives the correct intensity. The actual intensity of the spot in the Laue pattern is estimated in terms of the intensity of the "spot" from some other family of planes of nearly the same interplanar distance. It is often necessary to tilt the crystal in order to get both "spots" on the same film. In such a case the amount of tilt is found by trial. This often necessitates taking many Laue patterns of the same crystal. In some cases, this makes the Laue method rather laborious and time-consuming. An empirical approximate method has been proposed by Wyckoff,(42) by which the relative intensities of all the spots may be calculated in terms of the so-called "normal decline" of intensity with increase in angle. The calculations differ from those of expression (37) by the factor $\left(\frac{d_{hkl}}{n}\right)^{2.35}$ where d_{hkl} is the interplanar distance and n is the order of diffraction.

Summary

The Laue method may be summarized by saying that it uses the data of x-ray diffraction as a means of choosing between the various atomic groupings which will give the observed symmetry characteristics of the crystal. The maximum use possible is made of symmetry considerations and the minimum use is made of x-ray data. In the x-ray portion of the method a single stationary crystal is used and the x-ray beam employed contains all possible wavelengths from those barely able to pass through the x-ray bulb and crystal down to the quantum limit imposed by the voltage across the x-ray tube.

(To be continued)

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(42) R. W. G. Wyckoff, "The Structure of Crystals," (*American Chemical Society Monograph* series, 1924. Chem. Catalog Co., New York.).

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Elec. Rev., Dec. 5, 1924; v. 95, pp. 845-847.

Electric Current Rectifiers

Mercury Vapour Sub-Stations.
Engr., Nov. 28, 1924; v. 138, p. 622.
(From a paper before the Institution of Electrical Engineers.)

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Austin Constant-Current Motor for Ship Auxiliaries.
Engng., Nov. 28, 1924; v. 118, pp. 734-735.
(Describes equipment manufactured by Messrs. Gilbert Austin, Ltd., Glasgow.)

Electric Drive—Steel Mills

Large-Powered Rolling Mill Drives.
Engng., Dec. 19, 1924; v. 118, p. 842.
(Short description of a 32-ton flywheel Ilgner set built by an English firm.)

New Sheet Bar and Hot Strip Mills. Prentiss, Fred L.
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(Illustrated description of machinery in an Otis Steel Company mill.)

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Lamp Efficiency and Life Tests. Skogland, J. F., and Myer, J. Franklin.
Elec. Wld., Dec. 20, 1924; v. 84, pp. 1302-1304.
(A summary of life tests, at the U. S. Bureau of Standards, on vacuum tungsten-filament incandescent lamps.)

Electric Motors, Railroad

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(Methods used by the Public Service Railway of New Jersey at its Newark shops.)

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Engng., Dec. 12, 1924; v. 118, p. 802.
(Short description of a device manufactured by Ferranti, England, for preventing the access of moisture to the oil of transformer tanks.)

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(Illustrated description of Cutler-Marsden equipment.)

Electricity—Applications—Agriculture

Progress in Rural Service Study—I. Perry, Allen M.
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(Outlines experimental work that is being done, with special data on the Red Wing, Minn., tests. Serial.)

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(A paper presented at the First World Power Conference.)

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(Short description of automatic plants of the Hydro-Electric Power Commission at Dams No. 8 and No. 9 of the Trent Valley Canal System.)

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(Presents data on losses due to leaky boiler settings, and the like.)

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(Presents results of tests.)

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(According to the preface, this book supplants the two volumes written jointly with the late Dr. Samuel Sheldon entitled "Direct-current Machines" and "Alternating-current Machines," and published in 1900 and 1902, respectively. The present volume treats both direct-current and alternating-current machines. It is intended especially for classroom work, but will be found useful as a text for self-instruction and as a reference book for those engineers whose work involves the occasional need for data on the operation of electrical machinery. The main subjects treated are: electric and magnetic circuits, direct-current machines, alternating currents and their circuits, alternating-current machines and transformers, and conversion apparatus.)

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(A review of the status of electric traction on the German State Railways at the beginning of 1924. Deals primarily with plant equipment, and locomotives and other rolling stock, but also discusses numerous theoretical considerations such as locomotive load characteristics, inductive interference, and the like. The various chapters are written by specialists who present valuable information drawn from their experiences in the operation of German railroads.)

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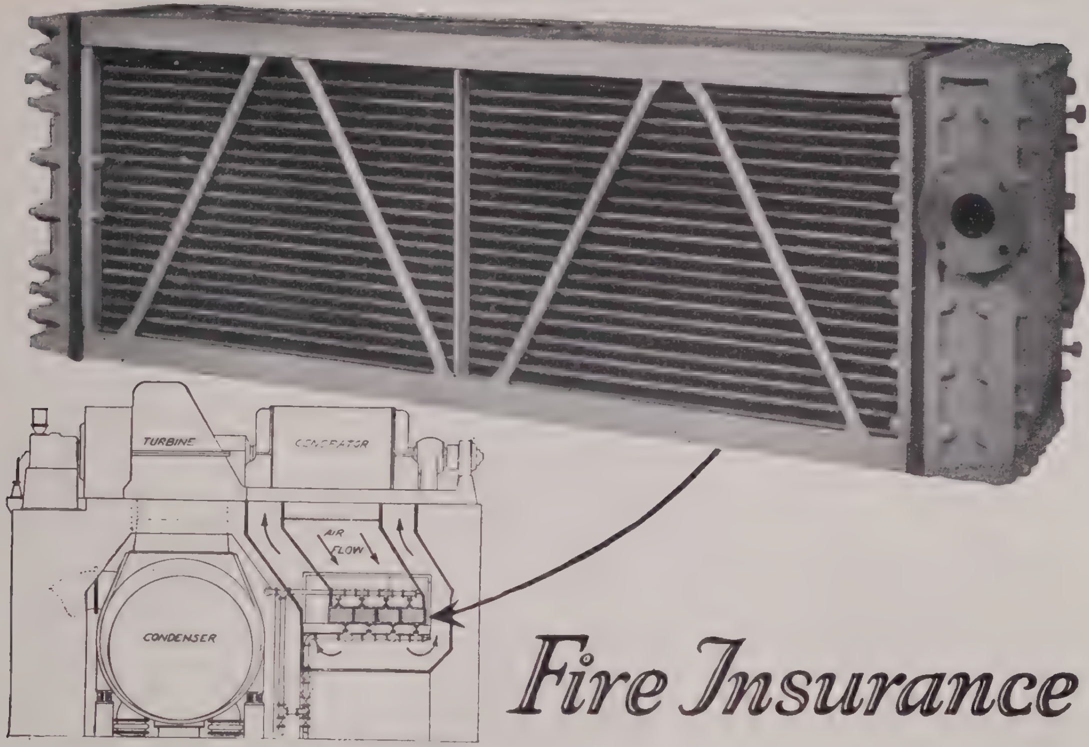

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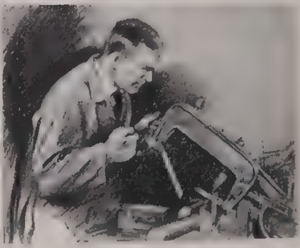

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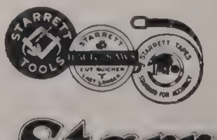

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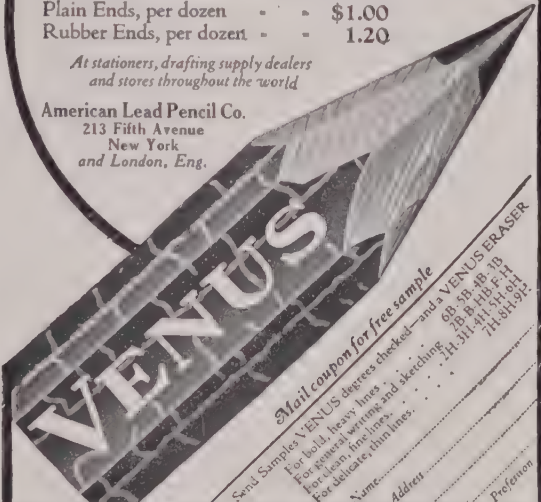

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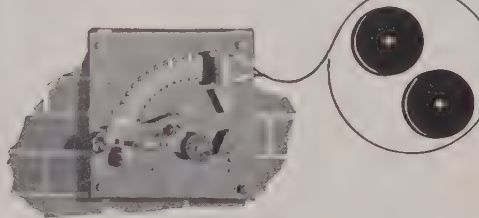

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Directory of Advertisers

Ajax Electrothermic Corp.	22
American Lead Pencil Co.	21
American Brass Co.	5
Audel & Co., Theo.	Inside B'k Cover
Babcock & Wilcox Co.	12
Biddle, James G.	12
Borne & Scrymser Co.	20
British Thomson-Houston Co.	16
Buffalo Forge Co.	15
Diamond Power Specialty Corporation	22
Diamond State Fibre Company	12
Drum, A. L. & Co	24
Electric Bond and Share Co.	16
Elliott Company	3
Foundation Company, The	24
General Electric Company	17, 18
General Radio Co.	12
Griscom-Russell Co., The	11
Indiana Steel and Wire Co.	20
Ingersoll-Rand Co.	2
Irvington Varnish and Insulator Co.	22
Keystone Lubricating Co.	15
Lidgerwood Mfg. Co.	11
Link Belt Company	Back Cover
Locke Insulator Corp.	7
Maqua Company	19
McClellan & Junkersfeld	24
Morse Chain Co.	Inside B'k Cover
National Carbon Co.	6
New Departure Mfg. Co.	9
Newport News Shipbuilding & Dry Dock Co.	14
Norma Company of America	13
Public Service Production Co.	24
Robinson & Co., Dwight P.	24
Ryle & Co., Wm.	22
Sargent & Lundy	24
Schutte & Koerting Co.	10
Smith Co., S. Morgan	13
Spaulding Fibre Co., Inc.	21
Speer Carbon Co.	20
Stackpole Carbon Co.	4
Starrett Co., The L. S.	20
Stevens, John A.	24
Stone & Webster	1
Wellman-Seaver-Morgan Co.	14
Wheeler Condenser & Eng. Co.	Inside Ft. Cover
Wheeler Mfg. Co., C. H.	10
White Engineering Corporation, The J. G.	22

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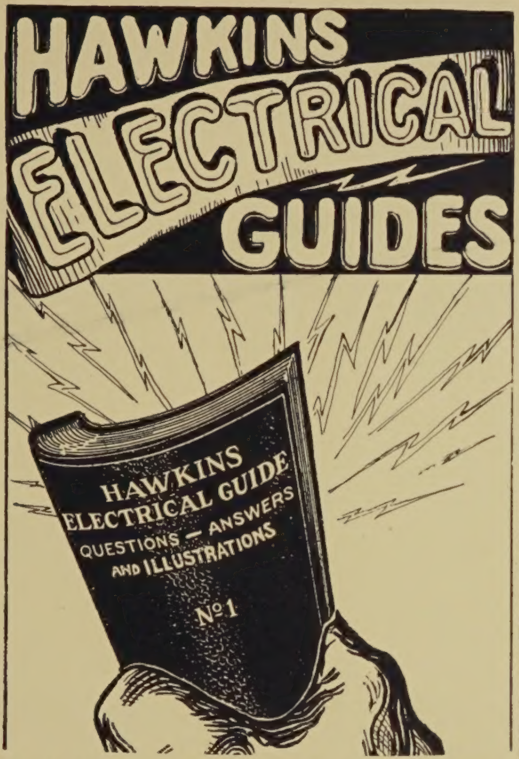

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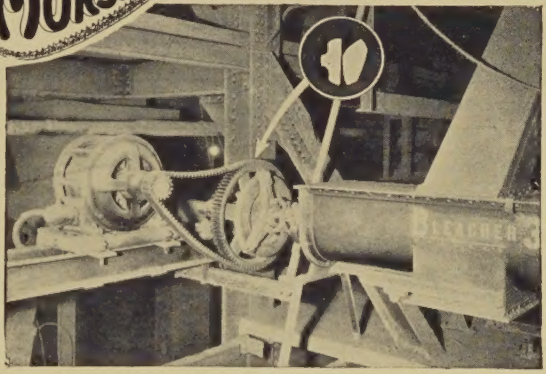

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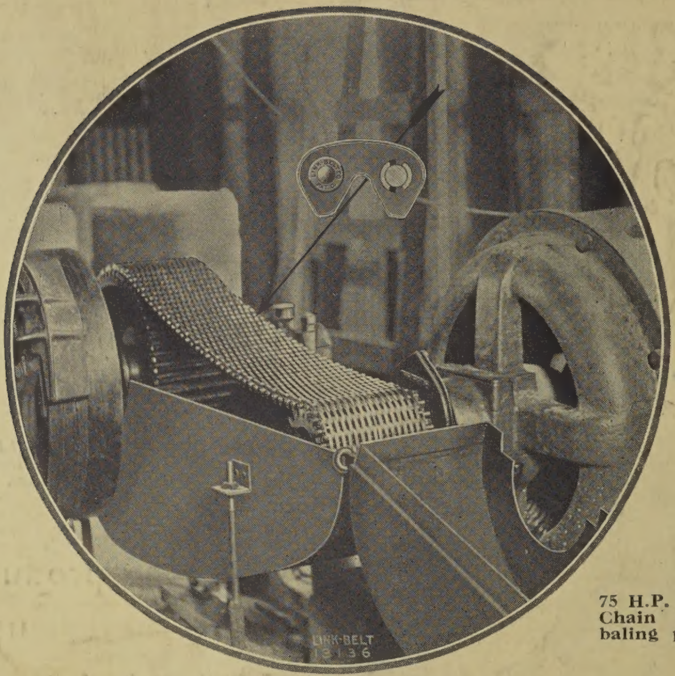

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